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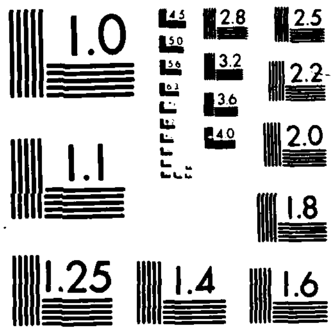
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A SLAM SIMULATION BASE ESCAPE MODEL

USING RESPONSE SURFACE METHODOLOGY

THESIS

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Approved for public release; distribution unlimited

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THESIS

Presented to the Faculty of the School of Engineering

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Table of Contents

List of Figures

List of Tables

Abstract

This thesis presents a microcomputer compatible, base escape nuclear survivability model specifically designed to compute pre-launch survivability. It computes the number of aircraft surviving from single or multiple bases under SLBM attack. The model concentrates on simulating the process from alert to take-off. In particular, it models the statistical variability of crew reaction time, engine start time, taxi time, and take-off separation time under various levels of readiness. Nuclear overpressure, gust, and thermal fluences are determined through response surface methods and aircraft survivability is derived from cumulative log-normal damage functions. Its advantages over current base escape models are microcomputer compatibility and stochastic representation of the pre-launch survivability timing variables.

A SLAM SIMULATION BASE ESCAPE MODEL USING RESPONSE SURFACE METHODOLOGY

I. Introduction

Problem Background

One of the primary deterrents to the Soviet Union's espoused goal of world-wide domination is the threat of nuclear retaliation imposed by the U.S. nuclear arsenal. This arsenal is constrained by arms control agreements and the high cost of purchasing and maintaining these weapons. Therefore, the United States must effectively utilize a limited number of weapons and delivery systems to support its national objective of defending the United States and its interests from foreign aggression.

To employ these limited assets, the United States has developed a Triad of weapon systems consisting of bombers, Inter-Continental Ballistic Missiles (ICBM), and Sea Launched Ballistic Missiles (SLBM). Each leg of the Triad has its own unique advantages and disadvantages. One of the primary advantages of the bomber leg is its flexibility. During times of increasing tension, the bombers can be launched as a show of force and recalled as needed.

Bombers also suffer from several disadvantages. Unlike submarines which can remain hidden until commanded to launch their missiles, bombers are placed at a limited number of

locations which cannot be hidden from an enemy. Compared to land-based missiles that maintain a nearly 100% alert posture and can be launched in minutes, bombers require from hours to days to configure all aircraft for their nuclear deterrent role. This preparation time for non-alert sorties is much longer than the time necessary for a nuclear warhead to be delivered and destroy a bomber base. To minimize these disadvantages, a portion of the bombers and their supporting tankers are maintained on alert where they can be launched within a matter of minutes. However, even in this advanced state of readiness, these bombers are still vulnerable to being destroyed before they can get safely away from the base environment.

These factors have led to the development of analytical models that evaluate the effects of nuclear attacks on the bomber leg of the Triad. Developers of these models hypothesize that SLBMs provide the primary threat to the bombers since their flight times (about 10-15 minutes) can be less than half of an ICBM's. With these short flight times, SLBMs can be used to directly attack the bomber bases in an effort to destroy the bombers during their escape from the base.

Figure 1 gives a pictorial overview of the base escape process. The process begins with missile breakwater and subsequent detection by U.S. sensors. A delay is then encountered while confirmation and decision making takes place. Afterwards, notification is sent to the base(s) to

launch their aircraft. The crews respond to the aircraft, start engines, taxi to the runway, and take-off. The escape process ends when the surviving aircraft have escaped the last of the attacking weapon effects.

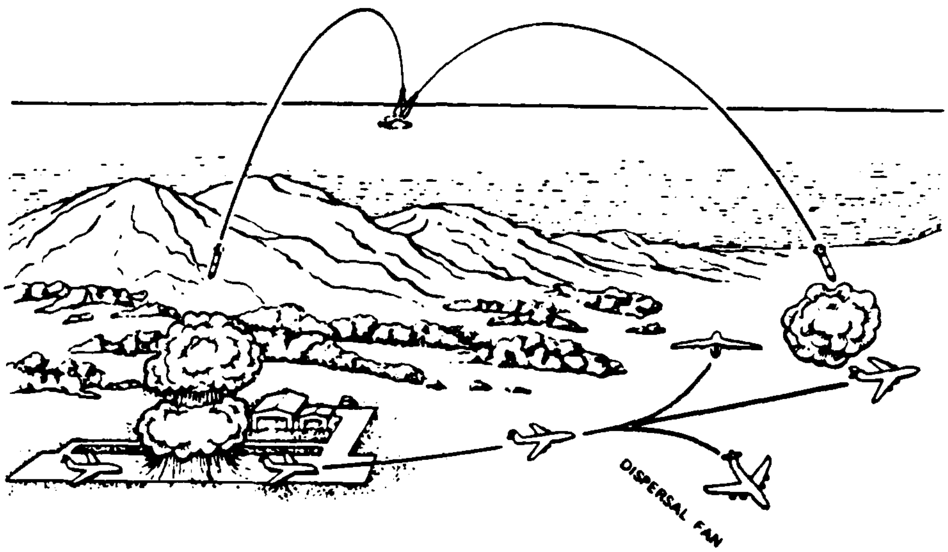


Figure 1. Base Escape Process (8:4)

Specific Problem

Air Force strategic warfare planners need a fast and accurate method to compute SAC alert aircraft Pre-Launch Survivability (PLS) over a wide range of possible scenarios. For the purpose of this thesis, pre-launch survivability is that portion of the base escape process that begins when the crews are given launch notification and ends after the effects of the first (over the runway) warhead detonation subside.

Presently, the Air Force has multiple base escape models that provide overall fleet survivability, but they

concentrate on modeling pattern attacks on escaping aircraft rather than the single "over the field" burst scenario. Most base escape models assume a fixed "reaction" time that encompasses crew response time, engine start time, and taxi time (17:22; 23:7). This assumption does not account for normal variation in these three time parameters. Another common assumption with present base escape models is the aircraft will queue up for the runway without delay and take-off with exact (non-varying) separation (23:7). Again this assumption ignores variance and relies on "average" data.

Specific Tasking. This thesis was developed in response to a request made by the Bomber Tactics Branch at Headquarters Strategic Air Command (HQ SAC/XOBB). The Bomber Tactics Branch would like a model developed that will compute SAC-wide alert force Pre-Launch Survivability. This model should utilize presently available exercise data and run on a Tempest certified Z-150 microcomputer.

Overall Objective of Research

The objective of this thesis is to develop a fast running, microcomputer compatible, simulation model that will accurately compute PLS. The model must examine crew reaction time, engine start time, taxi time, queuing effects, and aircraft separation times with enough detail to allow planners to vary these parameters to determine optimum base escape tactics.

Specific Objectives of Research

1. Identify the important events and network processes involved in simulating the base escape process.

2. Evaluate the appropriate timing variables and their distributional characteristics.

3. Develop a microcomputer compatible, SLAM simulation base escape model that computes SAC-wide pre-launch survivability.

4. Minimize the amount of computer code required to compute aircraft probability of survival.

5. Verify and validate this model with previous base escape models.

6. Analyze the simulation's results and compare with results of existing models.

Assumptions

1. The primary base escape threat is from sea launched ballistic missiles.

2. The enemy is assumed to have some knowledge of our base escape tactics and timing.

3. The enemy will employ his weapons in an optimum manner to maximize destruction of escaping aircraft.

Limitations

The model is unclassified and thus contains "generic" approximations of its base escape parameters. In order to be utilized at HQ SAC/XOBB as a base escape simulator, the model's approximations of crew reaction times, engine start

times, taxi times, take-off separation times, departure profiles, and warhead arrival times will need to be updated.

To update the model, specific distributions will have to be fit to the classified exercise data that SAC maintains. These distributions should then be specified in the network portion of the SLAM simulation code. Specific aircraft departure profiles are also needed to generate the actual response surface that computes aircraft probability of survival. Finally, the real world escape parameters and warhead arrival times will need to be inserted into the data files that are read-in during the simulation.

Organizational Overview

Following the introductory chapter, this thesis contains a literature review that reviews base escape reference information (Chapter 2), describes the methodology developed to solve the base escape problem (Chapter 3), describes the simulation in detail (Chapter 4) and its response surface (Chapter 5), analyzes simulation results (Chapter 6) and finishes with conclusions and recommendations (Chapter 7).

II. Literature Review

Base Escape Methodologies

The overall approach to researching the base escape problem involves comparing and contrasting previous efforts. Base escape methodologies fall into two general categories: Monte Carlo simulation and deterministic algorithms. These two categories refer to the methods used in accounting for the effects that the nuclear detonations have on the escaping aircraft.

Monte Carlo Simulation. The first method, Monte Carlo simulation, can model problems as closely as the physical situation and input variables are known (17:12). This method treats the input parameters as random variables whose values are chosen randomly from specified probability distributions. Using a repetitive calculation routine, the results of encounters between escaping aircraft and the effects of the attacking weapon(s) are totaled and divided by the total possible outcome space. The resulting probability of survival (Ps) is an average or expected value for aircraft survivability.

$$Ps = 1 - \frac{\text{Total Number of Kill Encounters}}{\text{Total Number of Encounters}} \qquad (1)$$

A full Monte Carlo simulation of all possible SAC escape bases, their aircraft, and the attacking SLBMs requires a massive number of iterations to attain sufficient

confidence in the value of Ps. The resulting computer processing requirements usually dictate that base escape Monte Carlo simulations be limited to single base scenarios.

Deterministic Algorithms. The second method for determining the bomber-weapon interactions, deterministic algorithms, usually produce a single answer that can be duplicated with identical runs. These models are generally faster running and better suited for multiple base scenarios.

The preferred deterministic approach to modeling nuclear effects on escaping aircraft is referred to as the "cookie cutter" or vulnerability envelope method. This method is used by the Defense Nuclear Agency in the Handbook for Analysis of Nuclear Weapon Effects on Aircraft, Volume I (10:27).

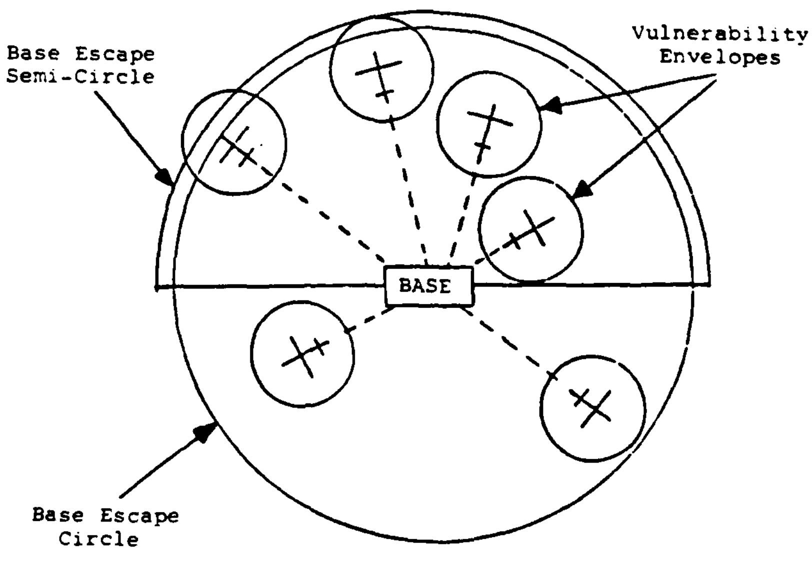


Figure 2. Aircraft Vulnerability Envelopes and Base Escape Circle (17:8)

As seen in Figure 2, each escaping aircraft has a vulnerability envelope (area) such that any detonations inside of this envelope will result in its destruction. Correspondingly, any detonations outside of the envelope (area) are assumed to not affect the aircraft.

With the assumption that both the escaping aircraft and attacking warhead detonations are randomly located within the base escape circle (the circular area around the base that the aircraft can disperse into before weapon detonation), probability of aircraft survival can be computed using the following equation:

$$Ps = 1 - \frac{\text{Total of lethal weapon areas}}{\text{Area available to escaping aircraft}} \tag{2}$$

An important part of the cookie cutter analysis is the way that the vulnerability areas are determined. Normally, the region of vulnerability is considered to be the "sure-safe" envelope. This envelope outlines the 98% probability of survival zone and is considered to be a conservative (thereby a larger area) estimate. Some methods like GETAWAY further define the vulnerability envelope by modeling the probability transition zone between sure-safe, a 98% survival rate, and sure-kill, a 2% survival rate (17).

Other deterministic algorithms, like the SAC SuperCalc routine, determine the aircraft survival rates by assuming a single burst scenario and drawing a weapon kill radius

around the base (26). The routine then locates each aircraft in its escape sequence at the moment of detonation. The single survival measure is whether the aircraft is inside or outside the kill radius.

Existing Models

Table I contains a listing of current survivability models that are in use by Department of Defense agencies. This table shows the methodology used in the models and whether the model is able to simultaneously compute survivabilities for single or multiple bases. Two of the models, FLEE and QUANTA are presently used by the Aeronautical Systems Division to evaluate the survivability of present and future strategic airborne systems.

The FLEE and QUANTA models represent the two primary approaches to base escape modeling. FLEE models an attack on a single base and its escaping aircraft through a repetitive Monte Carlo simulation process that keeps track of random bomber-weapon encounters (3:374). QUANTA looks at an attack on multiple bases and uses a deterministic "cookie cutter" approach to define lethal areas (1:6). This approach determines survivability by dividing the total lethal areas by the total dispersal area available to the escaping bombers. Both of these models are main-frame computer intensive and can take as much as 3600 CPU seconds (FLEE) to run a SAC-wide escape scenario (17:44).

In addition to these efforts, there are two other

TABLE I

Current Survivability Models

NAME	DEVELOPER/ AGENCY	THREAT EFFECTS	METHODOLOGY	RESULTS
FLEE	BDM Corp./ AFOTEC	Overpressure Thermal Radiation	Monte Carlo Single Base	Probability of exceeding spe- ified hardness levels
QUANTA	AFWL	Overpressure Thermal	Cookie Cutter Envelopes	% Surviving (Optimizes weapon allocation)
FLUSH	ASD	Overpressure Gust Thermal	Monte Carlo Multiple Bases	% Surviving
SIMPLS	General Research Corp.	Overpressure Gust Thermal	Monte Carlo and Cookie Cutter Envelopes Multiple Bases	% Surviving
BASEM	ANSER/ Hq USAF	Overpressure Gust Thermal	Cookie Cutter Envelopes Multiple Bases	% Surviving
STRAT SURVIVOR	SA/ Hq USAF	Overpressure Thermal	Monte Carlo and Cookie Cutter Envelopes Multiple Bases	% Surviving

deterministic algorithms that are fast running and easy to use. The first, a classified SAC SuperCalc program, calculates pre-launch survivability by combining alert force exercise data (averages) with threat estimates to derive average fleet survival rates (26). The second algorithm, GETAWAY, developed by an AFIT thesis effort, successfully introduced parametric analysis to base escape analysis.

In 1983, MacGhee and Williams, at the request of the Survivability Branch of Aeronautical Systems Division, addressed the problem of computing base escape survivability in their GETAWAY thesis (17). Using classical deterministic weapon effects routines, this effort produced an interactive computer algorithm that calculates survival rates from pattern attacks on the escaping aircraft. They were successful in producing a model that could individually evaluate any of 20 base escape parameters. This model gives an expected probability of survival for each input scenario and is very efficient, with running times of 20 CPU (VAX 11/785) seconds and turn-around times of 15 minutes. The model was shown to be effective in ranking the effects of changes in parameters, but the overall survivability figures were not considered to be reliable because its Ps values did not correlate well with Ps values of other models (17).

Drawbacks. The models in Table I suffer from three primary drawbacks. First, they are main-frame computer intensive, requiring lengthy set-up and turn-around times. Secondly, the models view base escape from a

macro viewpoint and disregard the important processes taking place before the aircraft take the runway for departure. Finally, the survivability figures for the same scenario vary substantially among the models because of their differing approaches to computing survivability (17:45).

The remaining deterministic algorithms suffer from a lack of computational robustness. Although the GETAWAY model provides an interactive method to rapidly vary the input parameters of base escape, it is guaranteed only to rank order the results instead of producing a meaningful survivability figure. On the other hand, SAC's PLS generator uses actual response data to determine the survivability of aircraft from some specified threat and can only be used for limited parametric computations.

Response Surface Methodology

To reduce the amount of computer code necessary to produce usable survivability data, response surface methods can be incorporated into the base escape process. Except for the SAC PLS generator which crudely models aircraft/weapon interactions, present models all require at least mini-computer resources and are not suitable for down-sizing into a micro. Response surface methodology can provide this down-sizing capability by reducing thousands of lines of code into a few lines of regression equations.

Response surface methodology provides a way to

mathematically model solution sets or surfaces generated by experimentation. In the case of base escape, models provide experimental survival data that can be fit to a "response surface" of solutions to the input escape parameters. In this way, the solution set or response surface essentially replaces the model and its experimentally obtained solutions (18:2.1).

RSM hypothesizes that there is a functional relationship of the form:

$$Y = f(X1, X2, X3, \ldots\ldots, Xn) \qquad (3)$$

where Y is the response or dependent variable that is a function of the n independent variables X1,X2,X3,.....,Xn. This multidimensional function can be linear or non-linear, but it must be continuous over the region of interest. As an example, a response surface can be visualized as a series of contours, very similar to the hills and valleys of a contour map (14:1-1).

To apply RSM, an experimental design is selected that will accurately describe the response surface with a minimum number of data points. This accuracy is measured by how well a least squares fit of the data compares to the "true" function being investigated.

By accomplishing these steps, the weapon effects routines of a proven base escape model can be reduced to a simple regression equation. This reduction in computer code should allow the SLAM model to run efficiently on a

microcomputer.

Chapter Summary

This literature review chapter surveyed the various methods which have been and can be used in analyzing the base escape problem. The next chapter will describe the methodology developed for solving the base escape problem.

III. Methodology

System Description

The base escape process has two primary phases. The first phase is the pre-launch phase which begins at SLBM break-water and ends when the aircraft starts its take-off roll. The final phase is the take-off and escape phase which begins at take-off roll and ends when the last attacking SLBM detonation effects subside.

Pre-launch survivability is a subset of the base escape process. It includes portions of both the pre-launch phase and the final phase. PLS begins when the crews are given launch notification and ends after the effects of the first warhead detonation subside. It accounts for the effects of a single burst over the runway and not the effects of subsequent pattern attacks on departing aircraft.

A depiction of the base escape phases and their component parts are shown in Figure 3. Missile breakwater starts the process and is followed chronologically by detection, alert, crew response, engine start, taxi, take-off, and finally aircraft safe-escape or destruction.

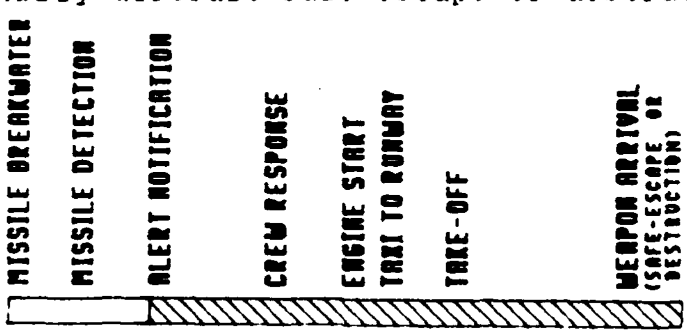


Figure 3. Base Escape Time Line

Pre-Launch Phase. After missile break-water, there is an initial time delay in launching the alert force due to missile detection, data processing, decision making, and alarm activation delays. Base escape modeling usually starts at the time of alarm activation and accounts for the time between break-water and alarm by designating a fixed delay time.

At alarm activation crews respond to the aircraft, start engines, and taxi to take-off. These three processes are formally called Crew Reaction Time (CRT), Engine Start Time (EST), and Taxi Time (TT) respectively. Each of these times are regularly exercised and recorded by base, aircraft type, and force readiness.

By statistically analyzing the exercise data, the distributional nature of each of these times can be determined and evaluated. These three distributions can then be utilized in modeling the base escape pre-launch phase.

Take-off and Escape Phase. Immediately prior to take-off, the aircraft must first queue up to take the runway(s) and second, obtain minimum safe spacing between aircraft for take-off. The queuing process involves alert aircraft parked in physically separate locations merging prior to or at the runway. Figure 4 shows this process with two physically separated parking areas for bombers and tankers.

After the aircraft are queued-up, the take-off process begins with the first aircraft starting its take-off roll

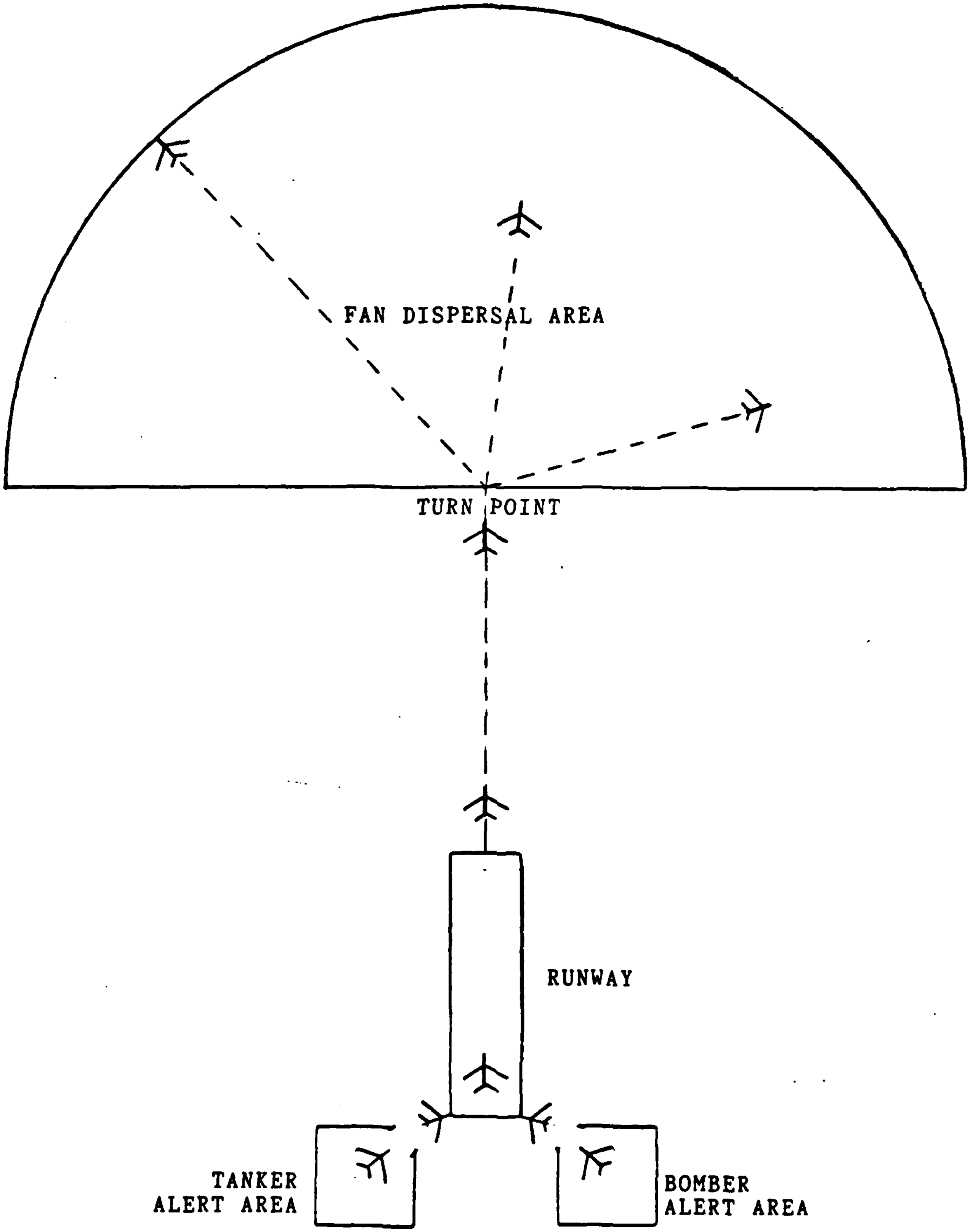


Figure 4. Queuing and Take-off/Escape Phase

and the other aircraft gaining minimum safe separation time between each other. This separation time is defined as the absolute minimum time that will insure engine blast and wake turbulence will have dissipated to a safe level between take-offs.

Once the aircraft are safely airborne, the threat from incoming SLBM warheads will decrease only as distance from the base (target) environment increases. Figure 4 shows the path that the aircraft follow while escaping from the base. At some specified distance from the runway, the aircraft reach the turn-point and fan out to avoid the effects of a possible multiple burst pattern attack. At this point, incoming warhead detonation(s) will begin to take its toll on the airborne aircraft.

It should be noted, that the minimum threat base escape attack scenario (a.k.a. PLS) assumes that the base (runway) is the single designated ground zero (aim-point). Thus, the airborne aircraft must first escape the "over the runway" blast environment. It is also hypothesized in full base escape scenarios that the Soviets might target multiple warheads in some kind of pattern attack away from the base in an attempt to destroy more escaping aircraft.

Only after the aircraft have escaped both the runway attack and the pattern attack (if any) will they be considered as having survived. The goal of base escape modeling is to arrive at a probability of survival for the escaping aircraft over the range of base escape parameters.

Measures of Merit

The principle measure of merit for any base escape scenario is the number of aircraft surviving the SLBM attack. It is also useful to determine the number of each type of surviving aircraft. For instance, if a model determines that 3 of 15 aircraft of a mixed B-52 and KC-135 force are destroyed, planners would need to know how many of each type of aircraft survive for overall force attrition estimates.

Of the two ways to determine force attrition, the most widely used is the "cookie cutter" approach. This approach uses nuclear weapons affects algorithms to determine a lethal radius from a weapon detonation. If the aircraft is within this lethal radius at detonation, it is killed. A further refinement to the cookie cutter approach determines individual probabilities of survival utilizing a log-normal probability of survival distribution and estimates of sure-safe and sure-kill intensities required to kill individual aircraft. These individual probabilities of survival are combined to derive an estimate of the overall number of aircraft surviving.

Elements of Base Escape Modeling

To model the base escape process, the various base escape elements must be quantified as accurately as possible and then modeled correctly. The elements for this model are broken down into timing probability distributions and

aircraft/weapon effects attrition parameters. This break down allows a straight forward insertion of the elements into the network simulation process.

There are four timing distributions and four attrition parameters that are modeled in this base escape simulation. The four timing distributions are modeled in the network portion of the simulation in order to obtain the time each aircraft begins rolling on the runway. The remaining parameters define the attrition environment that the aircraft will encounter when the detonation takes place.

Model Timing Distributions. The four model timing distributions are crew response time, engine start time, taxi time, and take-off separation time. These timing distributions determine how quickly the crews and aircraft can take-off after alert notification.

Crew Response Time. Crew Response Time (CRT) is defined as the time it takes for the crews to arrive at the aircraft after alert notification. The variability in response times is caused by crew dispersion around the base and the fact that the alert facility is some distance from the aircraft parking locations. CRT differences often occur between the bomber and tanker crews because their alert parking locations are often widely separated.

Crew response time is controlled by the readiness level of the alert force. It ranges from normal alert where the crews can be located throughout the base to "cockpit alert", the highest state of readiness. In this state, the crews

are onboard the aircraft, ready to start engines. This in effect reduces crew response time to zero.

Engine Start Time. Engine start time is the time it takes to start engines and prepare the aircraft for taxi. Aircraft starting times vary because of differences in engine ignition time, the type and number of engines, and weather conditions. There is also some variation between bombers and tankers which is caused by the bombers being more complex and encountering more problems during start.

Engine start time can also be controlled by the readiness level of the alert force. At higher states of readiness, the aircraft can be configured for "quick start" with all engines having starter cartridges installed. This configuration only reduces time to start compared with the highest readiness level when engines are already running (EST is zero).

Taxi Time. Taxi time is defined as the time it takes to taxi alert aircraft from their parking locations to the end of the take-off runway. Taxi time varies not only with distance to the runway, but speed and queuing effects must also be accounted for. The speed is normally "as fast as conditions will permit" and can vary greatly depending on the time of day (taxi speeds are slower at night) and weather conditions. Occurring simultaneously with the taxi process is the fact that both bombers and tankers are usually queuing up for the same runway. Since bombers always have priority for take-off, tankers are only allowed

to take-off on a non-interference basis with the bombers.

Taxi times can also be reduced by increasing the readiness of the alert force. This is accomplished by repositioning the aircraft from parking to the taxi ramps adjacent to the end of the take-off runway. Repositioning minimizes but does not eliminate taxi time and its accompanying queuing effects.

Take-Off Separation Time. Take-off separation is defined as the time difference (separation) between the consecutive aircraft as they begin their take-off roll. Normal separation time is 12 seconds between aircraft (12:1). This time varies due to crew error and increased separation requirements between bombers and tankers. For the purposes of this thesis, normal take-off separation is assumed to be a triangular distribution with a low of 10, mode of 12, and a high of 20 seconds. This assumption reflects the fact that separations less than 10 seconds are unsafe and greater than 20 seconds will create a bottleneck. The mode of this distribution is arbitrarily increased to 15 seconds between unlike aircraft, because separation needs to be increased between aircraft with different performance characteristics.

Hypothetical Distribution Assumption. Ideally, data would be collected, histograms would be generated, and distributions would be fitted to base escape data as part of the system modeling process. Since actual base escape data is classified SECRET, this simulation assumes that crew

response time, engine start time, and taxi time are normally distributed. Actual distributions and their parameters can be easily quantified and inserted into the simulation for classified production runs.

<u>Model Weapon Effects and Attrition</u>. Attrition of the escaping aircraft starts to occur at the first detonation (assumed to be over the runway) and ends as the last detonation effects subside. The model accounts for three primary detonation effects: overpressure, gust, and thermal. Aircraft tolerances for these effects are designated at the beginning of the model.

The four attrition parameters that define the weapon effects and their effects on escaping aircraft are: yield, Height of Burst (HOB), Circular Error Probable (CEP), and escape time (time from beginning take-off roll to weapon detonation). The weapon parameters of yield, height of burst, and circular error probable must be specified to allow the computation of lethal radii for the three detonation effects.

The final and most important attrition parameter in base escape modeling is the time from beginning the take-off roll until the first incoming detonation occurs. This time specifies a location dimension to the aircraft. The weapon effects computations will "fly" the escaping aircraft out specified profiles and locate the aircraft in relation to the weapon detonation. This is the last parameter that is needed to compute attrition due to weapon effects.

Base Escape Model Formulation

Figure 4 contains a depiction of the base escape process from the aircraft parking areas to the final dispersal fan. The aircraft are treated as SLAM entities that are created at time zero and travel through the system until the attacking warheads detonate. Aircraft attrition is then accounted for by inputing the aircraft's time since beginning take-off roll to the response surface-generated survival equations that determine whether the aircraft survives.

General SLAM Network Model Description. Chapter IV contains a detailed description of the SLAM network code and Figure 5 shows a general flow diagram for the base escape model. The beginning control statements establish the SLAM limits and initialize the global variables representing the five attrition/warhead parameters.

The simulation begins by the SLAM initialization process reading in the base data. This data contains the information on number of bomber and tanker aircraft, all time distributional parameters, number of take-off runways, and the time between warning and warhead detonation.

The network starts by creating the bombers and initiating the time delays caused by the crew response, engine start, and taxi processes. The bombers are then queued up for the single or double runway cases. This whole process is then repeated for the tankers. The aircraft are

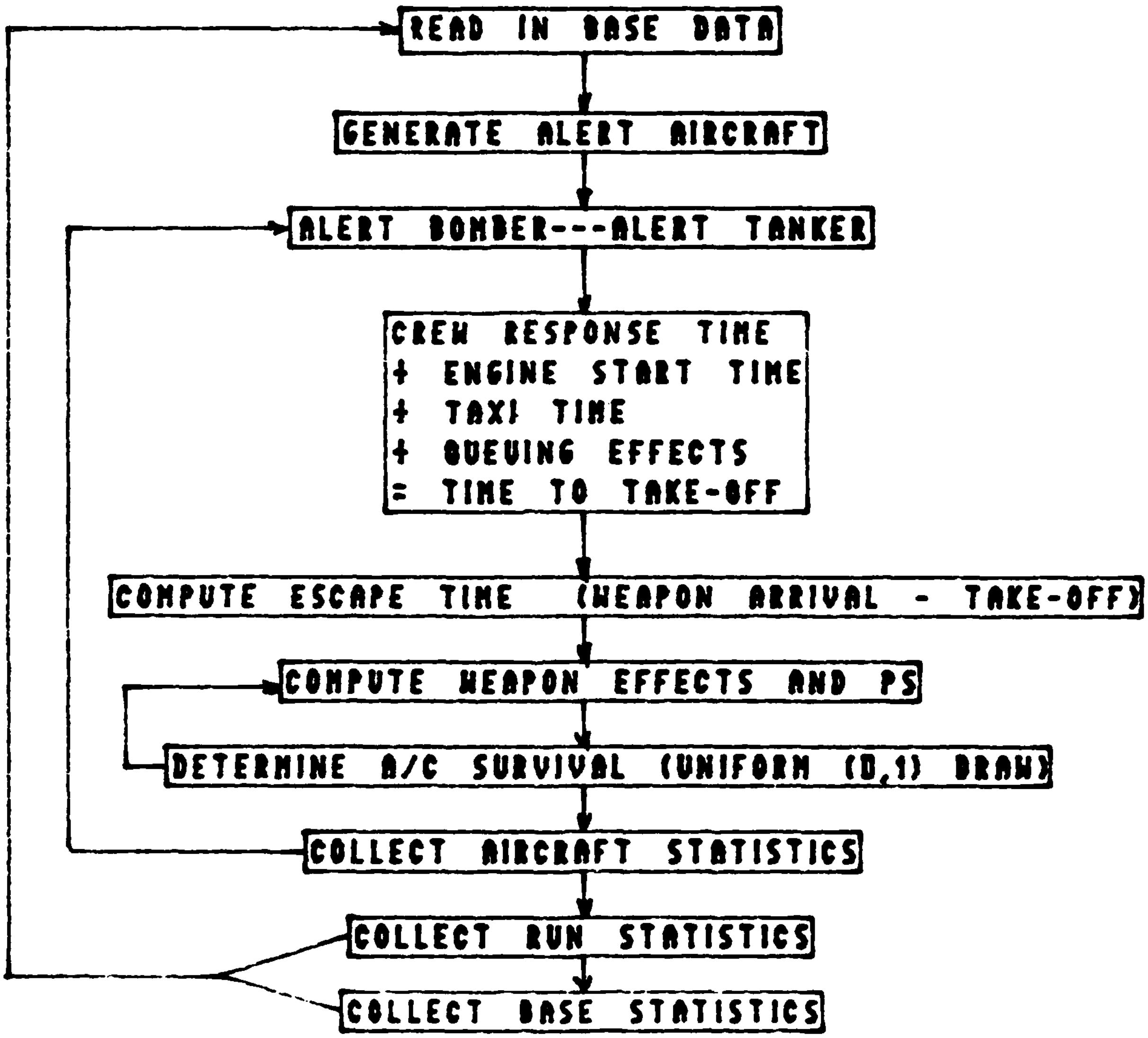


Figure 5. Simulation Model Flow Diagram

then simulated merging into a single or double runway, with bombers having priority, by routing both queues through a priority select process.

A take-off interval is then established through triangular timing distributions. The probability of survival for the aircraft is calculated by an event (EVENT 1,1) subroutine located in the Fortran code.

When all the entities are through the system or the "clock" runs out, the individual simulation will end. The aircraft survival counts are collected and the attrited aircraft are accounted for. The simulation is then replicated for variance reduction and the whole process is repeated for each base under evaluation.

Response Surface Development. As discussed in Chapter I, the goal of this thesis is to develop a fast running and easy to use model that produces verifiable survivability figures. The model should be able to be run parametric analyses on microcomputers. Its output survivability figures should compare closely with the detailed models in Table I (such as QUANTA or FLEE) and be able to utilize the actual response data used in the SAC Supercalc PLS generator.

By using SLAM simulation to model the base escape process and abbreviating the weapon effects routines, a fast running, microcomputer compatible model was developed. The reduction of weapon effects routines was accomplished through the use of Response Surface Methodology (RSM).

In applying RSM to the problem of reducing the weapon effects routines, the following five step process was accomplished:

1) Select the base escape model that provides the most efficient means of finding the weapon effects data.

2) Choose an experimental design that will minimize the number of data points required to generate a robust response surface.

3) Run the selected model the required number of times and gather the data.

4) Input this data to a statistical package to fit a least square regression to the data, maximizing R square for goodness-of-fit.

5) Input the regression equation into the SLAM model to compute the final probability of survival data.

Measurement and Design

The experimental design process for this base escape model is separated into two distinct parts. The first part is to design an experimental analysis of the SLAM network that determines the elapsed time between alarm notification and when the aircraft take the runway for launch. The second and more complex part is to set up the experimental design of the weapon effects model that determines whether or not each escaping aircraft survives.

Data Collection and Analysis. The distributions and parameters of the four timing stochastic variables (crew

reaction time, engine start time, taxi time, and take-off separation time) are determined from classified exercise data. Strategic Air Command collects exercise data for each of the time variables on almost a weekly basis. This readily available data can be grouped and histograms fit to determine their distributions and corresponding parameters.

The weapon effects parameters that are used to describe the detonation (yield, HOB, and CEP) are fixed throughout the simulation and have no distributional characteristics. Escape time, the fourth parameter, is determined in the SLAM network for each escaping aircraft. For these parameters, data points will have to be systematically varied over the ranges of each of the parameters. Other parameters, such as number of detonations, time between detonations, distance to turn-point, and fan dispersal angles, were not addressed as variables in this model.

Experimental Design--Simulation Network. The experimental design of the simulation network is limited to the use of variance reduction techniques and the computation of replications required for 95% confidence intervals on the number of aircraft surviving. Since the distributional nature of the timing variables are statistical representations of actual "real world" exercise data, any screening of the main distributional variables would make the simulation less robust (the users would not be able to vary deleted time distributions to see their overall effects). Also the four time distributions are assumed to

be independent, so there are no two factor interaction effects to screen.

Experimental Design--Weapon Effects. Since incorporation of a robust weapon effects program into the simulation would preclude model operation on a microcomputer, a multi-dimensional curve-fit or response surface was generated to provide needed survivability data. It was assumed that the response surface will be non-linear and probably a second order function of the form:

$$Y = B0 + B1X1 + B2X2 + B3X3^2 + B4X4^2 + \ldots\ldots \qquad (4)$$

To apply RSM to the problem of reducing the weapon effects routines, a deterministic base escape model, GETAWAY was used to calculate experimentally designed sets of Ps data points over the parametric ranges of interest. The response surface was generated by an automated multiple regression package, which produced weapon effects regression equations (11).

The experimental design of weapon effects is greatly simplified by the fact that the process is deterministic. Each combination of input parameters will yield only one answer. Since variance is eliminated, regression on the data points will yield the actual or true response surface. Any error effects are bias errors which represent the difference between the true function and fitted surface.

To fit a response surface, data points must be generated to fit a regression model. If the four nearly

continuous weapon parameters are limited to 10 discrete values apiece, a full enumeration of the event space would take 10,000 runs. Computational time (VAX 11/785) per weapon effects run takes 20 CPU seconds on a program like GETAWAY and 45 CPU seconds on QUANTA. To preclude accumulating an excessive amount of computer time, an experimental design process is utilized.

Normally, an experimental design of a four factor (parameter) system like this would involve initial screening using a fractional factorial design. This design process would highlight the significant factors and their various interactions. Fortunately, in the field of response surface design, this kind of problem has been resolved and simplified so that no screening (either full or fractional factorial) is required to assist in defining the response variable (probability of survival) in terms of its input parameters.

Various authors, including M.J. Box and Draper, have designed what is termed a "cube star plus center point" design that minimizes the number of data points required to create a robust response surface (7:738). This design is based on a 3^k design, with a center point included, which allows for the creation of second order (curved) and lower order response surfaces.

The number of data points required to define the surface is reduced because the design is orthogonal and rotatable. Each matrix row is a sample (data point) and

each column represents the domain (range) of the parameter of interest. This orthogonal design matrix creates a diagonal matrix when multiplied by its transpose (X'X). The orthogonal nature then generates independent regression coefficients.

The following abbreviated matrix (Table II) shows the optimal experimental design for a four factor, second order problem (see Chapter 4 and Appendix G for full design and all response variables). It requires only 25 data points since four of the cubic centers are repeated (5:460).

TABLE II

Four Factor Experimental Design

(Settings: +1 High, -1 Low, 0 Center)

Escape Time	Yield	HOB	CEP	
+1	+1	0	0	(example point)
-1	+1	0	0	
-1	-1	0	0	
+1	-1	0	0	
0	0	+1	+1	
0	0	-1	+1	
0	0	-1	-1	
0	0	+1	-1	
:	:	:	:	
:	:	:	:	
0	0	0	0	(cubic center)

For example, to calculate the first data point, the following parameters are input into GETAWAY: escape time is set at its highest setting (300 seconds); yield is also set

at its highest setting (1500 kilotons); height of burst is set at its middle setting (8000 feet); and circular error probable is set at its middle setting (.8 nautical miles), which produces an overpressure (response variable not shown) of 0.219 PSI.

Once the data is accumulated (following this design), the data points are input into a multiple linear regression package such as BMDP 9R to determine regression coefficients (11:264). The assumption of non-linearity is then tested through a three step process. The first step is to try to fit a simple linear response to the data. The second step is to add interactive coefficients to the model. Finally, second order terms are added. At each step, the adjusted R square, sum-of-squared errors, and corresponding residual plots are checked for model adequacy. The initial hypothesis is a second order model since most weapon effects are non-linear. Depending upon these results, additional transformations to the model variables may be needed for a good experimental fit.

Sample Size and Reliability. Because this is a discrete simulation, the number of replications required for the overall simulation is determined by the variability of the overall number of aircraft surviving. A confidence interval of 95% in conjunction with numerical analysis or operating characteristic curves are used to determine the number of replications required.

Variance Reduction Techniques. Two variance reduction techniques will be utilized to reduce the variability due to the random number streams. The first is to test the model with antithetic streams which will create negative correlation between observations. The second technique is to run multiple random number streams with no initialization between runs. This in effect creates separate random number streams for each replication of the model.

Chapter Summary

This chapter describes the methodology developed to solve the base escape problem by analyzing its component parts. The next two chapters will describe the simulation model in detail and analyze its response surface.

IV. Detailed Model Description

Introduction

This chapter will examine the SLAM simulation model in detail to give the reader a thorough background in the events and processes being simulated. If the reader accepts the model's face validity, and doesn't need the fine details, this chapter can be bypassed with little loss in continuity.

The detailed model description of this mixed network and discrete SLAM simulation will begin by defining the SLAM variables and showing where they are used. Afterwards, both the SLAM program statements and FORTRAN routines will be examined in detail, with particular emphasis on what is occurring to the aircraft entities as they traverse the simulation network.

Explanation of Variables

Appendix C contains a listing of all pertinent SLAM model variables and their individual explanations. SLAM variables XX(1) through XX(16) are the 16 pieces of data that describe the base being examined. These variables are initialized prior to each run by the INTLC subroutine in program MAIN.

Variables XX(17) through XX(19) and XX(22) through XX(27) are variables that define the weapon parameters and the sure safe, sure kill parameters of the escaping

aircraft. These parameters remain constant over the runs and are initialized by the INTLC control statements in the SLAM code.

Variables XX(28) through XX(34) provide the input and output parameters to both the EVENT subroutine and FORTRAN code that computes the aircraft probability of survival. The remaining three XX variables (XX(35) through XX(38)) are used to compute and report the number of aircraft surviving the attack.

There are only two attribute variables that are used in this simulation. ATRIB(1) is used to keep track of overall elapsed time and ATRIB(2) designates the type of aircraft. All other variables in the simulation are indigenous to the FORTRAN routines and will be explained in the FORTRAN section.

SLAM Simulation Program

This section explains in detail the model's SLAM simulation control and network statements that are located in Appendix A. Particular attention will be devoted to following the aircraft entities through the system under various scenarios. The explanation starts with the control statements that set up the simulation environment.

Simulation Control Statements. The first control statement, the GEN statement, is one of three types of control statements that the user will need to change when adapting this simulation to a SAC-wide base escape scenario.

Among other things, the GEN statement designates the number of runs to be executed. In the five base example, the base escape scenario for each base was replicated 20 times for a total of 100 runs. The number of replicates is determined from the variability of the number of surviving aircraft (see the variance reduction section). In this case, the GEN statement designated 100 runs with a single summary report at the end of the simulation.

The other two control statement types that will need to be adapted to the user's needs are the INTLC and STAT statements. The nine INTLC statements will need to have updated weapon parameters and aircraft vulnerability parameters. The STAT statements will need to be expanded to include the total number of escape bases in a SAC-wide scenario.

The remaining control statements set-up the file space and initialize the simulation. Neither of these statements will need to be changed unless the simulation is altered drastically.

<u>Simulation</u> <u>Network</u>. The essence of this base escape model lies in the network simulation routine. Initially, two separate sets of entities are created that represent the alert bombers and tankers. These entities encounter a series of delays prior to reaching the runway to take-off. At take-off, the simulation "clock" is checked to determine the entity's (aircraft's) time from alert. This time from alert is input to a FORTRAN routine that determines

probability of survival given all the escape parameters. Random draws then determine whether or not the entity (aircraft) survives the three nuclear effects. Finally, the entities are sorted and accounted for.

Entity Creation. Since the entity creation process cannot vary, the simulation arbitrarily creates 25 bomber and 25 tanker entities per base. The correct number of aircraft per base is achieved by terminating all excess entities (over the correct number). This process does limit the number of bombers or tankers per base to a maximum of 25. If the user wants to simulate more aircraft, field 6 of the CREATE node(s) must be changed.

Timing Distributions. All of the delays the entities encounter after alert (creation) and before queuing up for the runway are assumed to be normally distributed. Delays corresponding to crew reaction time, engine start time, and taxi time all take place at ACT (activity) nodes. Since the bomber and tanker timing distributions can differ, there are two sets of timing distributions, one for bombers and the other for tankers. After the user fits distributions to the exercise data, these ACT nodes will need to be changed to correspond to the real (classified) stochastic nature of the timing variables.

Runway Queuing Process. The entity creation and delay process is relatively straight forward compared to when the aircraft start to queue up for the runway. At this point, the simulation has two groups of entities, bombers

and tankers, randomly arriving in a position to take-off. Unfortunately, in the single take-off runway case, both groups need to merge together and await their turn to launch. Complicating this process is the fact that bombers have take-off priority over tankers.

This situation is resolved by a priority queuing process that first routes the bomber and tankers to separate files (queues 1 and 3) and then a SELECT node allows the bombers to precede the tankers. This node will release a tanker for take-off only when bombers are not awaiting take-off.

Occurring simultaneously with the select process is the separation delay between launching aircraft. This delay causes queuing and allows the select process to occur. The amount of delay time is generated from a FORTRAN USERF (user function) and takes place at the ACT node immediately following the SELECT node.

The second case of runway queuing occurs with dual take-off runways. In this case, there is no merging between the bombers and tankers, but each aircraft still has to await its turn to launch within its respective group. The model accounts for this scenario by routing the bombers and tankers to separate queues and subjects the groups to the same type take-off delays encountered with the single runway case (waiting times will be reduced with two take-off runways).

Take-off and Survival. When the aircraft entities are released for take-off, the "clock" is checked and three probabilities of survival are generated for each aircraft. A random draw process then determines whether or not the individual aircraft survive the three nuclear weapon effects. For example, given an overpressure Ps for an aircraft is .69, an ACT node compares it with a random draw from a uniform (0,1) distribution. If the draw is less than 0.69, the aircraft survives (the process is repeated for the remaining gust and thermal Ps's).

The surviving aircraft entities are sorted and collected by aircraft type for output reports. These reports collect all relevant statistics, including the number and type of aircraft that survive and their average escape times. Two SLAM summary reports for the single and multiple base cases are included in Appendices E and F.

SLAM FORTRAN Program

Program MAIN contains three subroutines and two functions that enable the simulation to accurately portray the base escape process. These routines were required because the SLAM network could not efficiently simulate all of the base escape processes.

FORTRAN Subroutines. The three subroutines INTLC, EVENT, and OTPUT read in the base data, calculate nuclear fluences, and collect output statistics.

Subroutine INTLC. This subroutine reads the input

data file, one base at a time, and loads the data into an array. The array is used to initialize variables XX(1-16) before each run. Along with initialization, the subroutine has a statement that allows multiple replications per base. This statement is set to 20 replications per base which approximates a 95% confidence interval that the number of surviving aircraft will be correct within 0.5 aircraft. It will be up to the user to set the number of replications per base (given real world data).

Subroutine EVENT. This subroutine calculates nuclear weapon fluences and their respective probabilities of survival on the escaping aircraft. The individual fluence calculations are regression equations that were developed by response surface methodology (see Chapter 5). Once overpressure, gust, and thermal fluences are calculated, calls are made to the PRBSVL function which converts fluences into probability of survival measures.

Subroutine OTPUT. This subroutine collects the overall and individual base escape statistics. It also supplements the four histogram collect nodes contained in the network. On the last run of the simulation (presently run 100), it collects all accrued statistics for the SLAM summary report (called by the GEN control statement). If the user wishes to change the overall number of runs, line 8, 10, and 15 will need to be updated.

FORTRAN Functions. The two functions, PROBSVL and USERF, calculate probabilities of survival and take-off

intervals between launching aircraft, respectively.

Function PROBSVL. This function is called from the EVENT subroutine to compute aircraft probability of survival given the weapon fluence and the aircraft's sure safe and sure kill parameters. The function fits the input fluence to a log normal distribution with sure safe equal to a .98 probability of survival and sure kill equal to a .02 probability of survival.

Function USERF. This function is called from the network queue service activities to compute the take-off interval between aircraft. Take-off intervals are selected from one of two hypothetical triangular distributions that represent approximate "real world" aircraft separations. Two distributions were chosen because the take-off interval is slightly longer for unlike aircraft. For example, a KC-135 must delay take-off slightly longer behind a B-52 than behind another KC-135. This function also accounts for both single and dual runway take-offs.

Chapter Summary

This chapter examined the simulation model and its FORTRAN computer code in detail. The next chapter will show the development of the response surface equations that were used in FORTRAN portion of the simulation.

V. Response Surface Development and Analysis

Introduction

In an effort to reduce computer code, response surface methodology was employed in developing the base escape model. Response surface techniques reduced the deterministic weapon effects routines in GETAWAY (17) from nearly two thousand lines of code to three regression equations. This reduction in code allowed the five base simulation (100 runs) to execute on an IBM PC AT in 2 minutes and 9 seconds or a Zenith Z-100 in 4 minutes and 8 seconds.

This chapter will trace the development of the response surface from its experimental design stage through the intermediate data gathering and processing stages to the final stage of analyzing the results. The development of the response surface generally follows the example shown in Smith and Mellichamp's article, "Multidimensional Parametric Analysis Using Response Surface Methodology and Mathematical Programming as Applied to Military Problems" (24:601-615).

Experimental Design

As stated in Chapter 3, the experimental design for this response surface is a design from Box and Behnken's article, "Some New Three Level Designs for the Study of Quantitative Variables" (5:460). This design assumes the

response equations will be in the form:

$$\begin{aligned} \text{Weapon Fluence} = {} & b_0 + b_1 T + b_2 Y + b_3 H + b_4 C \\ & + b_5 T^2 + b_6 Y^2 + b_7 H^2 + b_8 C^2 \\ & + b_9 (T \times Y) + b_{10} (T \times H) + b_{11} (T \times C) \\ & + b_{12} (Y \times H) + b_{13} (Y \times C) + b_{14} (H \times C) \end{aligned} \qquad (5)$$

where weapon fluence is the response variable (Ps cannot be directly computed), b_n are the variables' coefficients, T = time between aircraft take-off and weapon detonation, Y = weapon yield, H = height of burst, C = circular error probable.

The appropriateness of Box and Behnken's design (and others like it) for deterministic response surfaces was the subject of two thesis efforts. Manacapilli and Ishihara confirmed that a design that minimizes both variance and bias, such as Box and Behnken's, could produce an effective response surface that was both an accurate fit to the true response surface (full enumeration of data) and a minimum data point design (18; 14).

Since this is a second order design, each parameter is required to have three levels or settings (24:604). To properly input a response surface design into a regression package, the levels must be normalized into a coded form where +1 is the parameter's maximum value, -1 is its minimum value, and 0 is its middle value. These parameters and their levels are shown in Table III.

TABLE III

Input Parameter Levels

Input Parameters	Levels (Codes)		
Escape Time (T SEC)	0 (-1)	150 (0)	300 (+1)
Weapon Yield (Y KT)	100 (-1)	800 (0)	1500 (+1)
Height of Burst (HOB FT)	3000 (-1)	8000 (0)	13000 (+1)
Circular Error (CEP NM)	0.3 (-1)	0.8 (0)	1.3 (+1)

The coded and non-coded parameter levels of the full experimental design are shown in Table IV. The non-coded levels provide the input settings to GETAWAY that return values for the response variables (weapon fluence).

TABLE IV

Experimental Design Coding

	Coded				Non-Coded			
Run	T	Y	HOB	CEP	T	Y	HOB	CEP
1	+1	+1	0	0	300	1500	8000	0.8
2	-1	+1	0	0	0	1500	8000	0.8
3	-1	-1	0	0	0	100	8000	0.8
4	+1	-1	0	0	300	100	8000	0.8
5	0	0	+1	+1	150	800	13000	1.3
6	0	0	-1	+1	150	800	3000	1.3
7	0	0	-1	-1	150	800	3000	0.3
8	0	0	+1	-1	150	800	13000	0.3
9	+1	0	0	+1	300	800	8000	1.3
10	-1	0	0	+1	0	800	8000	1.3
11	-1	0	0	-1	0	800	8000	0.3
12	+1	0	0	-1	300	800	8000	0.3
13	0	+1	+1	0	150	1500	13000	0.8
14	0	-1	+1	0	150	100	13000	0.8
15	0	-1	-1	0	150	100	3000	0.8
16	0	+1	-1	0	150	1500	3000	0.8
17	+1	0	+1	0	300	800	13000	0.8
18	-1	0	+1	0	0	800	13000	0.8
19	-1	0	-1	0	0	800	3000	0.8
20	+1	0	-1	0	300	800	3000	0.8
21	0	+1	0	+1	150	1500	8000	1.3
22	0	-1	0	+1	150	100	8000	1.3
23	0	-1	0	-1	150	100	8000	0.3
24	0	+1	0	-1	150	1500	8000	0.3
25	0	0	0	0	150	800	8000	0.8

Data Collection

The GETAWAY model was selected to provide data for the response surface. It is easy to use, well documented, and developed for parametric analyses. Two modifications were made to the GETAWAY code to extract the required design data. The first modification insured that the runway was targeted with a single burst and the second changed the model's output to weapon fluence measures instead of Ps.

The second modification was required because weapon effects Ps functions act like a step function and a response surface would have to be broken into three piece-wise continuous functions (25). An attempt was made to fit a single response surface, but only 6 of the 25 data points provided any useful curve-fitting data (Ps between 0 and 1).

After modification, GETAWAY's classical weapon effects routines provided direct fluence data for overpressure, gust, and thermal effects. Appendix G contains a listing of GETAWAY's output from the non-coded input data. This output provides the input data for regression analysis.

Model Assumptions. Three tactical assumptions were made during the GETAWAY data gathering runs. The first two assumptions insured that the aircraft turn (fan) point was approximately one mile off the end of the runway and the aircraft fanned out over 180 degrees. The second and more critical assumption was in designating the single aircraft climb profile. A relatively "generic" climb and acceleration profile was chosen for both the bombers and

tankers. This choice of profiles is critical since it determines how far the aircraft are from the runway when detonation occurs.

Model Drawbacks. Presently, GETAWAY is not a widely accepted base escape model. It's primary competitors, QUANTA and FLEE, are considered to be the benchmark base escape models for multiple and single base modeling by the Defense Nuclear Agency and Aeronautical System Division's Survivability Branch (15). Unfortunately, due to time constraints, neither of these models could be fully investigated and adapted to the parametric needs of response surface methodology.

Data Processing

The final step in deriving the response surface equations is to input the three 25 case sets into a multiple linear regression program. The independent variables are the coded levels while the dependent variable is weapon fluence. Two multiple regression packages, BMDP 2R (Stepwise) and BMDP 9R (All Possible Subsets), were used to process the data (11:251,264).

Results

BMDP 2R and 9R produced the regression equations for overpressure, gust, and thermal effects. The Equations 6 through 8 below are the coded (normalized) regression equations that were computed by the multiple regression programs. Equations 9 through 11 convert the coded

variables into non-coded or real world equations.

$$\text{Overpressure} = .80169 - 4.93833t + 1.33967y + 1.14008h - 3.1225ty + 3.51425th + 4.3283t^2 \quad (6)$$

$$\text{Gust} = 2.27439 - 66.96809t + 68.12125th + 65.024t^2 \quad (7)$$

$$\text{Thermal} = 1.98339 - 42.58492t + 13.56258y - 37.029ty + 21.15675th + 40.81503t^2 \quad (8)$$

$$\text{Coded Time } (t) = \frac{(\text{Non-Coded Time } (T) - 150)}{150} \quad (9)$$

$$\text{Coded Yield } (y) = \frac{(\text{Non-Coded Yield } (Y) - 800)}{700} \quad (10)$$

$$\text{Coded HOB } (h) = \frac{(\text{Non-Coded HOB } (H) - 8000)}{5000} \quad (11)$$

The three regression equations and conversions were input into the FORTRAN portion of the simulation model. They directly calculate overpressure, gust, and thermal fluences given model inputs of escape time, yield, and height of burst.

Analysis of Results

The regression of the design data show that a response surface can be fit to weapon effects in a base escape scenario. One input parameter, circular error probable, did not significantly effect any of the response variables. As a result both multiple regression packages dropped CEP from the final equations.

The primary measure of this response surface's effectiveness is the multiple R square value, which is the

percentage of total variation in the weapon fluences that is explained by the factors in the equation. In this analysis, overpressure had the highest R square value of .89. The other two effects, gust and thermal, had R squares of .70 and .88 respectively.

Chapter Summary

This chapter showed the development and analysis of the simulation model's response surfaces. The next chapter will analyze the simulation results and verify and validate the model.

VI. Analysis of the SLAM Simulation Model

Introduction

The analysis of this simulation will begin by examining the results from initial model experimentation. Afterwards, the SLAM output from two full simulation scenarios will be analyzed. The chapter will conclude with a discussion of model verification and validation.

Experimentation

Initial experiments on this simulation model used five bombers and five tankers for the escaping force. To reduce the complexity of initial runs, arbitrary probability of survival estimates were inserted to eliminate variability from the FORTRAN weapon effects routines. Each run was ended approximately 400 seconds after the last aircraft reached the runway for take-off to insure that no entities were caught in the network at the end simulation time. For this simulation, four separate random number streams were used for the various distributions. In each case the default seeds were used.

Sample Size Calculation. Initially, a pilot run of ten replications was made to determine the proper sample size. Using a missile arrival time of 450 seconds, the Standard Deviation (SD) for the number of surviving aircraft was .82. To reduce this variation, hypothesis testing of the mean with variance unknown was accomplished. The maximum

standard deviation goal was set to 0.5 aircraft with a confidence interval of 95 percent because most analyses will require rounding to integer (whole) aircraft. The following statistical formula calculates the number of runs required to reduce the variation (13:284):

$$\text{Number of Replications} = \frac{(T * SD)^2}{VG^2} \qquad (12)$$

where T is the t-statistic with alpha equal to .05 and n-1 (n is the original number of replications) degrees of freedom, SD is the standard deviation, and VG is the variance goal in SD's.

Using this formula, the number of required replications for the experiment increased to fourteen. This technique was used again with the full simulation scenarios where the number of replications increased to 18 (rounded up to 20).

Initial Output Analysis. The results of the 450 second impact time showed an average of 7 aircraft surviving the missile attack. When the crew notification occurred 580 seconds prior to the missile attack, almost all of the aircraft survived the attack. This was due to the higher probability of survival resulting from the aircraft being further from the base.

Further inspection of the results showed the maximum average time for which a bomber waited to takeoff was 6.6 seconds, while the maximum time for a tanker was 12.1 seconds. This was expected since bomber aircraft are given

priority to takeoff if both a bomber and tanker are waiting for takeoff. However, there were some runs when the average waiting time was longer for bombers and than for tankers. This occurred because the tankers were sometimes able to start engines and taxi before the bombers. This allowed the first tankers to takeoff before a queuing problem with the bombers and later tankers occurred. The runs for which the bombers had a shorter average waiting time in the queue resulted when bombers and tankers arrived at the runway at about the same time.

These initial runs along with SLAM entity traces indicated that the basic flow of the entities through the network was correct. In the final model, three major changes were incorporated along with the input of the response surface Ps calculation routines. First, the response surfaces eliminated the need to account for aircraft inside or outside the turn-point. Second, difficulties in network modeling take-off separation delays required the creation of the USERF FORTRAN subroutine. Finally, allowances for dual runway take-offs were incorporated into the network code.

Model Results

The final model changes were incorporated into the SLAM program found in Appendices A and B. To test the finished model, two base escape simulations were conducted. The first simulation evaluated a single base and the second

evaluated five bases. Both simulations replicated each base 20 times to obtain 95% confidence interval estimates for the number of surviving aircraft. The complete SLAM summary outputs for each simulation are shown in Appendices E and F.

Both the single and multiple base simulations represent excursions to test how well the simulation executes. The single base data is the same as the first base in the five base example.

In the multiple base simulation, two of the bases have dual runway take-offs and two others have only one type of aircraft to launch. Each of the bases have different weapon arrival times to simulate widely separated bases or different launching submarines. Finally, the parameters of the timing distributions (CRT, EST, and TT) have been varied to show realistic differences between bases.

Base Survival Statistics. Table VI, Multiple Base SLAM Output Statistics, contains the SLAM "Statistics for Variables Based on Observation" outputs for both the single and five base simulation. It represents the primary statistics gathered by the base escape simulation model. These statistics are defined below:

ELAP TIME (Elapsed time)--average time in seconds to take-off for all aircraft.

ESCAPE TIME--average time in seconds to take-off for surviving aircraft.

BMBR SURV TIME (Bomber survival time)--average time in seconds to take-off for surviving bombers.

TNKR SURV TIME (Tanker survival time)--average time in seconds to take-off for surviving tankers.

AVG # AC ESCAPE--average number of aircraft that escape from all bases.

AVG # BMR ESCAPE--average number of bombers that escape from all bases.

AVG # TKR ESCAPE--average number of tankers that escape from all bases.

BASE X BMR ESCAPE--average number of bombers that escape from base "X".

BASE X TKR ESCAPE--average number of tankers that escape from base "X".

The first statistic, elapsed time, gives the user the average time (and variability) for alert aircraft to reach the take-off point. The next three statistics (escape time, bomber survival time, and tanker survival time) show the contrasting times (and their variabilities) required for aircraft survival. The remaining statistics account for the total and individual numbers of aircraft surviving at the bases. For the single base simulation, the statistics are equal to the base 1 statistics for the multiple base simulation.

Since the input data of the multiple base simulation was intended to test the limits of the model, the results are biased towards low aircraft survivability. This low survivability is caused by the relatively short warhead arrival times. Table V shows the input data for the five base simulation and Table VI is the SLAM statistics for the multiple base simulation. A comparison of Tables V and VI

indicates that of the 46 alert aircraft in the five base scenario, only 25.6 survived with 16.7 bombers and 8.9 tankers surviving (the single base only had 8.5 of 15 aircraft survive). The table also shows the distribution of surviving aircraft by base.

TABLE V

Multiple Base Simulation Input Data

Base	#Bombers	#Tankers	Wpn Arrival Time (sec)	#Runways
Base 1(Sim #1)	7	8	480	1
Base 2	5	5	400	2
Base 3	6	6	450	1
Base 4	4	0	600	1
Base 5	0	5	530	1
Totals	22	24	(46 total aircraft)	

TABLE VI

Multiple Base SLAM Output Statistics

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
ELAP TIME	.330E+03	.679E+02	.206E+00	.987E+02	.503E+03	920
ESCAPE TIME	.296E+03	.571E+02	.193E+00	.145E+03	.476E+03	513
BMBR SURV TIME	.287E+03	.597E+02	.208E+00	.145E+03	.476E+03	334
TNKR SURV TIME	.314E+03	.468E+02	.149E+00	.200E+03	.412E+03	179
AVG # AC ESCAPE	.256E+02	.000E+00	.000E+00	.256E+02	.256E+02	1
AVG # BMR ESCAPE	.167E+02	.000E+00	.000E+00	.167E+02	.167E+02	1
AVG # TKR ESCAPE	.895E+01	.000E+00	.000E+00	.895E+01	.895E+01	1
BASE 1 BMR ESC	.610E+01	.641E+00	.105E+00	.500E+01	.700E+01	20
BASE 1 TKR ESC	.245E+01	.110E+01	.449E+00	.100E+01	.500E+01	20
BASE 2 BMR ESC	.220E+01	.951E+00	.432E+00	.000E+00	.400E+01	20
BASE 2 TKR ESC	.600E+00	.883E+00	.147E+01	.000E+00	.300E+01	20
BASE 3 BMR ESC	.505E+01	.686E+00	.136E+00	.400E+01	.600E+01	20
BASE 3 TKR ESC	.220E+01	.128E+01	.582E+00	.000E+00	.500E+01	20
BASE 4 BMR ESC	.335E+01	.671E+00	.200E+00	.200E+01	.400E+01	20
BASE 4 TKR ESC	.000E+00	.000E+00	.100E+05	.000E+00	.000E+00	20
BASE 5 BMR ESC	.000E+00	.000E+00	.100E+05	.000E+00	.000E+00	20
BASE 5 TKR ESC	.370E+01	.801E+00	.217E+00	.200E+01	.500E+01	20

Histograms for Time Statistics. Figures 6 and 7 contain the last two of the four histograms (see Appendix F for all histograms) that are maintained on the time statistics shown in Table VI. These histograms show how the statistics vary over the number of observations. For example, in the multiple base case, the figures show that the average surviving bomber started its take-off roll approximately 287 seconds after alert, while the average surviving tanker started its take-off roll approximately 314 seconds after alert.

```
                        **HISTOGRAM NUMBER 3**
                            BMBR SURV TIME

OBS  RELA   UPPER
FREQ FREQ   CELL LIM 0        20        40        60        80       100
                     +    +    +    +    +    +    +    +    +    +    +
  3  .009  .160E+03  +                                                 +
 16  .048  .190E+03  +**C                                              +
 23  .069  .220E+03  +***  C                                           +
 55  .165  .250E+03  +********     C                                   +
 66  .198  .280E+03  +**********           C                           +
 57  .171  .310E+03  +*********                     C                  +
 54  .162  .340E+03  +********                              C          +
 34  .102  .370E+03  +*****                                       C    +
  9  .027  .400E+03  +*                                            C   +
 14  .042  .430E+03  +**                                               C
  2  .006  .460E+03  +                                                 C
  1  .003  .490E+03  +                                                 C
  0  .000  .520E+03  +                                                 C
  0  .000    INF     +                                                 C
---                  +    +    +    +    +    +    +    +    +    +    +
334                  0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
BMBR SURV TIME	.287E+03	.597E+02	.208E+00	.145E+03	.476E+03	334

Figure 6. Multiple Base Bomber Survival Time

```
                          **HISTOGRAM NUMBER 4**
                              TNKR SURV TIME

OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80        100
                    +    +    +    +    +    +    +    +    +    +    +
  0  .000  .160E+03 +                                                 +
  0  .000  .190E+03 +                                                 +
  5  .028  .220E+03 +*                                                +
 14  .078  .250E+03 +****C                                            +
 23  .128  .280E+03 +******     C                                     +
 37  .207  .310E+03 +**********           C                           +
 48  .268  .340E+03 +*************                     C              +
 27  .151  .370E+03 +********                                 C       +
 20  .112  .400E+03 +******                                          C+
  5  .028  .430E+03 +*                                                C
  0  .000  .460E+03 +                                                 C
  0  .000  .490E+03 +                                                 C
  0  .000  .520E+03 +                                                 C
  0  .000    INF    +                                                 C
---                 +    +    +    +    +    +    +    +    +    +    +
179                 0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TNKR SURV TIME	.314E+03	.468E+02	.149E+00	.200E+03	.412E+03	179

Figure 7. Multiple Base Tanker Survival Time

Output Observations. The SLAM output statistics contained in Table VI and Figures 6 and 7 are not easily read, but they contain a wealth of information. First of all, the time statistics and their histograms show how quickly the aircraft can reach launch position and the user can contrast this timing with what it takes to survive (by aircraft type).

The histograms also show the distributional nature of the time statistics. In the case of escape time (see Appendices E and F, Histogram 1), the histogram appears to be a normal

distribution. This is confirmed by the fact that the timing distributions that comprise escape time are all independent, normal distributions and when they are added together will produce a normal distribution.

The time to survival histograms also pass the test of reasonableness. These histograms slowly build-up to a peak and then drop-off quite rapidly. The slow build-up accounts for the fact that just a few "quick" aircraft launch first, but they all survive. The rapid drop-off indicates that those aircraft that were slow or encountered queuing delays, suffered a rapid drop in survival.

The final and most important statistics were the aircraft survival statistics. Although the number of aircraft that survive is the bottom line to any base escape study, the SLAM output does provide more information by showing the statistic's variance and its maximum and minimum values. This data is shown in last two columns of Table VI.

Verification and Validation

This model has been verified through documenting the computer code, drawing a flow diagram of the program, inspecting the computer code by more than one person, computing the results by hand, running multiple traces, and inspecting the results for reasonableness. The process of writing the documentation and drawing the flow diagram reduced the likelihood of making a logic error, which in

turn reduces problems later on. These steps also make it easier for someone else to follow the logic of the model.

Further verification was made by setting all of the probability distributions to their mean values. The results from this run compared closely with subsequent hand calculations. A trace was also conducted and each entity was followed through the simulation. All entities and their respective times in the system did as expected and no anomalies were found. Finally, the end results were inspected and found to be reasonable.

One area that the user will need to verify is the random number generators in his computer, especially if the simulation is being run on a microcomputer. The generators should be checked for adequate cycle length and that the numbers generated are truly random. These tests for uniformity and independence were not made for this project because the SLAM package on the VAX 11/785 has been previously verified.

Because there is limited real world data on how aircraft will respond during a nuclear attack, hypothesis testing and analysis of variance was not accomplished. Sensitivity analysis was made by changing the times and standard deviations for crew response time and aircraft engine start times. The change in results were as expected and no problems were found. The primary method (Touring Test) for validating the model was inspection of the results by the author based on his operational experience as a B-52

pilot.

Chapter Summary

This chapter examined initial model experimentation and final model results. It concluded with model verification and validation. The next chapter will discuss thesis conclusions and recommendations.

VII. Conclusion

Overview

The objective of this thesis was to develop a fast running, microcomputer compatible, simulation model that computes pre-launch survivability. To fulfill this objective, a two-step approach was taken. In the first step, the components that determine PLS were examined and coded into a SLAM simulation program. Second, response surface methodology was used to reduce classical base escape weapon effects routines to a simplified set of regression equations. The combination of these two steps achieved the objective in a scenario that is limited to "generic" approximations of the classified base escape parameters.

Conclusions

SLAM simulation is well suited for calculating pre-launch survivability because of its ability to process escaping aircraft as separate entities in a combined network and discrete simulation. The combined simulation allows the pre-launch phase to be viewed in the "micro" sense by the network portion, concentrating on simulating the processes occurring prior to take-off roll, and the take-off/escape phase to be viewed in the broad sense by the discrete FORTRAN weapon effects routines.

The network portion of the SLAM simulation enables the

user to vary timing distributions and their parameters with relative ease. In this case, the distributions are specified in the network and their parameters are read in from a base data file. Since the thesis is unclassified, "generic" normal distributions were chosen to model the time variables. When the user adapts the model to real world data, the distributional nature of the time variables must be determined and inserted into the network code.

To determine the distributional nature of the time variables (crew reaction time, engine start time, and taxi time), the timing data for each level of readiness at each base, must be collected and analyzed. This data has been collected and grouped by readiness level in SAC SAFETAP files. The analysis begins by processing these data files through a curve fitting program which will fit a distribution and determine its parameters at a specified confidence level. These distributions and their parameters are then input to the simulation.

The model's discrete weapon effects routines will also need to be updated to reflect real world data. The primary difference will be to use actual SAC aircraft escape profiles in generating weapon effects response surfaces. Although this process is quite involved, requiring a knowledge of response surface methodology and base escape modeling, this thesis has shown that it is both feasible and practical.

Fortunately, the development of a weapon effects

response surface is, at a minimum, incrementally workable. This means that data describing how weapon effects vary in response to changes of input parameters should provide some predictive capability under most circumstances. Eventually, through experimentation and regression transformations, a response surface can be generated that will predict weapon effect and corresponding aircraft probability of survival for the given input parameters.

Recommendations

The model developed by this thesis proved that SLAM simulation in combination with response surface methodology could be used to model a portion of the base escape problem on a microcomputer. The logical next step is to broaden the application of these methods.

Other Base Escape Models. To broaden the applicability of this model, response surfaces should be fit to the weapon effects data provided by more widely accepted base escape models. The response surfaces were developed with a base escape model that quickly produced data over the range of the target parameters. Other models such as QUANTA or FLEE produce more widely accepted base escape survivability data and should be used to generate future response surface inputs. Unfortunately, the output data of these models is restricted to aircraft probability of survival and direct response surface input is difficult (see Direct Ps Calculation below).

Escape Profiles. The single escape profile used to generate the response surfaces was only applicable to an undefined bomber and tanker aircraft category. Since SAC needs to determine survivabilities of many categories of aircraft including B-52's, KC-135's, B-1's, E-4's, and their variants, response surfaces could be derived for each category.

Alternately, a single surface could be developed by adding a profile dimension to the response surface derivation. Adding this parameter to the problem will increase the number of data points required to define a response surface by a factor of slightly less than two.

As profile categories increase, the SLAM code will need to be adjusted appropriately. Presently, the simulation only accounts for two types of aircraft with the same profile category. Changing the discrete FORTRAN code and "cloning" the SLAM entity creation/processing network can easily handle the increase in both aircraft types and profiles.

Pattern Attacks. Multiple weapon pattern attacks on individual bases and their escaping aircraft can also be added to the derivation of the response surface. This will upgrade the model into what is normally considered a full base escape simulation.

Since most base escape models optimally allocate pattern attacks to minimize the number of escaping aircraft, fitting a response surface should duplicate the allocation.

Like the profile case, adding a pattern attack will increase the number of dimensions or parameters of the response surface by one.

Direct Ps Calculation. Aircraft probability of survival as a function of distance from the detonation is assumed to follow a cumulative log normal distribution. Since the slope of this distribution varies dramatically, it is difficult to derive a second order polynomial equation that will accurately predict Ps. As a result, this thesis fit regression surfaces to the monotonically decreasing (as distance increases) weapon effects rather than probabilities of survival.

There are two methods that could be used to derive Ps functions directly. The first method involves breaking the survival function into three piecewise continuous segments. The three segments (zones) would be sure-safe, sure-kill, and the transition zone between them. This method appears to be time consuming, but relatively easy to compute.

The second method of directly computing Ps functions involves accomplishing exponential data transformations prior to performing the regression analysis. Unfortunately, this transformation process may not guarantee the orthogonality that the minimum data point designs require. This method could save time, but it is computationally complex and may not provide an accurate predictor of Ps.

Benefits. There are at least three potential benefits from implementing these recommendations. The first and most

important benefit is that full base escape simulations could be conducted on a microcomputer. Secondly, strategic planners could have the added ability to rapidly change base escape parameters and evaluate the resulting changes in force survivability. Finally, base escape tactics can be tested without tasking field units and aircraft.

APPENDIX A

SLAM Control and Network Statements

```
GEN,SCLARK,BASE ESCAPE,11/12/85,100,N,N,,N,YES/100,72;
LIMITS,5,5,100;
INTLC,XX(17)=800;                      YIELD
INTLC,XX(18)=8000;                     HEIGHT OF BURST
INTLC,XX(19)=0.8;                      CIRCULAR  ERROR
INTLC,XX(22)=1.0;                      SS OVERPRESSURE PSI
INTLC,XX(23)=5.0;                      SK OVERPESSURE PSI
INTLC,XX(24)=50.0;                     SS GUST FT/SEC
INTLC,XX(25)=150.0;                    SK GUST FT/SEC
INTLC,XX(26)=10.0;                     SS THERMAL CAL/SQCM
INTLC,XX(27)=25.0;                     SK THERMAL CAL/SQCM
STAT,5,AVG # AC ESCAPE;
STAT,6,AVG # BMR ESCAPE;
STAT,7,AVG # TKR ESCAPE;
STAT,8,BASE 1 BMR ESC;
STAT,9,BASE 1 TKR ESC;
STAT,10,BASE 2 BMR ESC;
STAT,11,BASE 2 TKR ESC;
STAT,12,BASE 3 BMR ESC;
STAT,13,BASE 3 TKR ESC;
STAT,14,BASE 4 BMR ESC;
STAT,15,BASE 4 TKR ESC;
STAT,16,BASE 5 BMR ESC;
STAT,17,BASE 5 TKR ESC;
;
;                     TIME UNITS IN SECONDS
;
NETWORK;
      CREATE,0,0,1,25;                 CREATE BOMBERS
      ASSIGN,XX(20)=XX(20)+1;
      GOON,1;
      ACT/1,,XX(2).GE.XX(20),NXT1;     ALERT BMBRS
      ACT;
      TERM;
NXT1  GOON;
      ASSIGN,ATRIB(2)=1;               BOMBER A/C ATTRIB
      ACT/2,RNORM(XX(3),XX(4),1);      BOMBER CRT
      GOON;
      ACT/3,RNORM(XX(5),XX(6),2);      BOMBER EST
      GOON;
      ACT/4,RNORM(XX(7),XX(8),3);      BOMBER TAXI
      GOON,1;
      ACT/5,,XX(16).EQ.2,DUA1;         DUAL RW(B)
      ACT;
QUE1  QUEUE(1),,,,SEL1;                BMBR SNGL RW Q
DUA1  QUEUE(2);                        Q-DUAL RW(B)
      ACT/6,USERF(1),,NXT3;            T/O INTVL(B)
```

```
         CREATE,0,0,1,25;                CREATE TANKERS
         ASSIGN,XX(21)=XX(21)+1;
         GOON,1;
         ACT/7,,XX(9).GE.XX(21),NXT2;    ALERT TNKRS
         ACT;
         TERM;
NXT2     GOON;
         ASSIGN,ATRIB(2)=2;              TANKER A/C ATTRIBUTE
         ACT/8,RNORM(XX(10),XX(11),3);   TANKER CRT
         GOON;
         ACT/9,RNORM(XX(12),XX(13),4);   TANKER EST
         GOON;
         ACT/10,RNORM(XX(14),XX(15),5);  TANKER TAXI
         GOON,1;
         ACT/11,,XX(16).EQ.2,DUA2;       DUAL RW(T)
         ACT;
QUE3     QUEUE(3),,,,SEL1;               TNKR SNGL RW Q
SEL1     SELECT,,,,QUE1,QUE3;            BOMBERS HAVE PRIORITY
         ACT/12,USERF(2),,NXT3;          B&T INTERVAL
DUA2     QUEUE(4);                       Q-DUAL RW(T)
         ACT/13,USERF(3);                T/O INTVL(T)
NXT3     COLCT(1),INT(1),ELAP TIME,12/140/30;
         ASSIGN,XX(34)=XX(1)-TNOW;       ACFT ESCAPE TIME
         EVENT,1,1;                      COMPUTE ACFT PS BY EFFECT
         ACT/14,,XX(31).GE.UNFRM(0,1),SUR1;  ACFT SURV OPRES EFFECT
         ACT/15;                         OPRES KILL
         TERM;
SUR1     GOON,1;
         ACT/20,,XX(32).GE.UNFRM(0,1),SUR2;  ACFT SURV GUST EFFECT
         ACT/21;                         GUST KILL
         TERM;
SUR2     GOON,1;
         ACT/22,,XX(33).GE.UNFRM(0,1),SUR3;  ACFT SURV THERM EFFECT
         ACT/23;                         THERM KILL
         TERM;
SUR3     COLCT(2),INT(1),ESCAPE TIME,12/160/30;
         ASSIGN,XX(35) = XX(35) + 1;
         GOON,1;
         ACT/24,,ATRIB(2).EQ.2,NXT7;     TNKR SURV
         ACT/25;                         BMBR SURV
         COLCT(3),INT(1),BMBR SURV TIME,12/160/30;
         ASSIGN,XX(36) = XX(36) + 1;
         TERM;
NXT7     COLCT(4),INT(1),TNKR SURV TIME,12/160/30;
         ASSIGN,XX(37) = XX(37) + 1;
         TERM;
         ENDNET;
INIT,0,600,NO,YES,YES;
FIN;
```

APPENDIX B

SLAM FORTRAN Code

```
$INCLUDE:'PRCTL.FOR'
$DEBUG
      PROGRAM MAIN
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/TPREV,TYPAC
      NCRDR=5
      NPRNT=0
      NTAPE=7
      OPEN(10,FILE='PROJ.DAT',STATUS='OLD')
      CALL SLAM
      STOP
      END
************************************************************************
*  THIS SUBROUTINE CALCULATES THE NUCLEAR WEAPON FLUENCES ON ESCAPING  *
*  AIRCRAFT GIVEN WEAPON EFFECT PARAMETERS AND THE TIME BETWEEN BRAKE  *
*      RELEASE AND WEAPON ARRIVAL (XX(34)).  THE FLUENCES ARE THEN     *
*       CONVERTED TO PROBABILITIES OF SURVIVAL WITH PRBSVL CALLS.      *
************************************************************************
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/TPREV,TYPAC
      XTIME(X)=(X-150)/150
      YIELD(Y)=(Y-800)/700
      HOB(H)=(H-8000)/5000
    1 IF (XX(34).LT.0.0)  XX(34)=0.0
*
*  OVERPRESSURE FLUENCE CALCULATION
*
      XX(28)=.80169
     +               - 4.93833*XTIME(XX(34))
     +               + 1.33967*YIELD(XX(17))
     +               + 1.14008*HOB(XX(18))
     +               - 3.1225*XTIME(XX(34))*YIELD(XX(17))
     +               + 3.51425*XTIME(XX(34))*HOB(XX(18))
     +               + 4.3283*XTIME(XX(34))**2
*
*  GUST FLUENCE CALCULATION
*
      XX(29)=2.27439
     +               -66.96809*XTIME(XX(34))
     +               +68.12125*XTIME(XX(34))*HOB(XX(18))
     +               +65.02420*XTIME(XX(34))**2
```

```
*
*  THERMAL FLUENCE CALCULATION
*
      XX(30)=1.98339
     +              -42.58492*XTIME(XX(34))
     +              +13.56258*YIELD(XX(17))
     +              -37.02900*XTIME(XX(34))*YIELD(XX(17))
     +              +21.15675*XTIME(XX(34))*HOB(XX(18))
     +              +40.81503*XTIME(XX(34))**2
*
*  PROBABILITY OF SURVIVAL CALCULATION
*
      XX(31)=PRBSVL(XX(22),XX(23),XX(28))
      XX(32)=PRBSVL(XX(24),XX(25),XX(29))
      XX(33)=PRBSVL(XX(26),XX(27),XX(30))
      RETURN
      END
************************************************************************
*  THIS SUBROUTINE READS IN THE ESCAPE DATA BY BASE AND FILLS AN ARRAY *
*              THAT REINITIALIZES VARIABLES XX(1-16).                  *
************************************************************************
      SUBROUTINE INTLC
      DIMENSION ARAY(16)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/TPREV,TYPAC
      DATA I/1/
      TPREV = 0
      TYPAC = 0
      IF (MOD(I,20).EQ.1) THEN
          READ(10,*) (ARAY(K),K=1,16)
      ENDIF
      DO 10 J=1,16
      XX(J)=ARAY(J)
   10 CONTINUE
      I=I+1
      RETURN
      END
************************************************************************
*THIS SUBROUTINE COLLECTS OVERALL AND INDIVIDUAL BASE ESCAPE STATISTICS*
************************************************************************
      SUBROUTINE OTPUT
      DIMENSION A(3)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/TPREV,TYPAC
      DATA I/1/
      DATA J/6/
      DO 10 L=1,3
          A(L)=CCNUM(L+1)/20
   10 CONTINUE
```

```
      IF (I.EQ.100.0) THEN
          DO 20 K=1,3
               CALL COLCT(A(K),K+4)
   20     CONTINUE
      ENDIF
      IF (MOD(I,20).EQ.1) J=J+2
      CALL COLCT(XX(36),J)
      CALL COLCT(XX(37),J+1)
      I=I+1
      RETURN
      END
************************************************************************
*  THIS FUNCTION COMPUTES PROB OF SURVIVAL GIVEN SS AND SK LEVELS AND  *
*  EFFECT LEVEL.  THE PROB OF SURVIVAL IS FITTED TO A LOG NORMAL DIST  *
*                   WITH SS=.02 KILL AND SK=.98 KILL.                  *
************************************************************************
      FUNCTION PRBSVL(SS,SK,EFF)
      REAL K
      IF(SS.EQ.SK) THEN
          PRBSVL=1.0
          IF(EFF.GT.SS) PRBSVL=0.0
          RETURN
      ENDIF
      S=SS
      K=SK
      IF(S.EQ.0.0) S=.0000001
      IF(K.EQ.0.0) K=0.0000001
      IF(EFF.EQ.0.0) EFF=0.0000001
      S=ABS(S)
      K=ABS(K)
      EFF=ABS(EFF)
      ALPHA=(ALOG(S)+ALOG(K))/2.0
      BETA=(ALOG(K)-ALOG(S))/4.108
      ZS=(ALOG(EFF)-ALPHA)/BETA
      Z=ABS(ZS)
      A=(1+.196854*Z+.115194*Z*Z+.000344*Z*Z*Z+.012527*Z*Z*Z*Z)**(-4.0)
      IF(ZS.GE.0.0) THEN
         PRBSVL=A/2.0
      ELSE
         PRBSVL=1.0-A/2.0
      ENDIF
      END
************************************************************************
*   THIS FUNCTION CALCULATES THE TAKE-OFF INTERVAL BETWEEN AIRCRAFT    *
************************************************************************
      FUNCTION USERF(N)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/TPREV,TYPAC
      W = TRIAG(10.,15.,20.,1)
      X = TRIAG(10.,12.,20.,2)
      Y = TNOW
      GO TO (1,2,3),N
```

```
*
*  BOMBER DUAL RUNWAY CASE
*
    1 IF ((Y-TPREV).GE.X) THEN
           TEMP1 = 0
         ELSE
           TEMP1 = X - (Y-TPREV)
      ENDIF
      USERF = TEMP1
      TPREV = Y + TEMP1
      RETURN
*
*  SINGLE RUNWAY CASE
*
    2 JJ = ATRIB(2)
      IF (JJ.EQ.TYPAC) THEN
          IF ((Y-TPREV).GE.X) THEN
              TEMP2 = 0
            ELSE
              TEMP2 = X - (Y-TPREV)
          ENDIF
        ELSE
          IF ((Y-TPREV).GE.W) THEN
              TEMP2 = 0
            ELSE
              TEMP2 = W - (Y-TPREV)
          ENDIF
      ENDIF
      USERF = TEMP2
      TPREV = Y + TEMP2
      TYPAC = ATRIB(2)
      RETURN
*
*  TANKER DUAL RUNWAY CASE
*
    3 IF ((Y-TPREV).GE.X) THEN
          TEMP3 = 0
        ELSE
          TEMP3 = X - (Y-TPREV)
      ENDIF
      USERF = TEMP3
      TPREV = Y + TEMP3
      RETURN
      END
```

APPENDIX C

SLAM Variable Definitions

<u>(XX) Variables:</u>

1. Warhead Detonation Time.
2. Number of Bombers.
3. Bomber Crew Reaction Time (CRT) Mean.
4. Bomber CRT Variance.
5. Bomber Engine Start Time (EST) Mean.
6. Bomber EST Variance.
7. Bomber Taxi Time (TT) Mean.
8. Bomber TT Variance.
9. Number of Tankers.
10. Tanker CRT Mean.
11. Tanker CRT Variance.
12. Tanker EST Mean.
13. Tanker EST Variance.
14. Tanker TT Mean.
15. Tanker TT Variance.
16. Number of Available Take-Off Runways (One or Two).
17. Weapon Yield (in Kilotons).
18. Weapon Height of Burst (in Feet).
19. Weapon Circular Error Probable (in Nautical Miles).
20. Bomber Creation Counter.
21. Tanker Creation Counter.
22. Sure-Safe Overpressure Effect (in PSI).
23. Sure-Kill Overpressure Effect (in PSI).
24. Sure-Safe Gust Effect (in FPS).
25. Sure-Kill Gust Effect (in FPS).
26. Sure-Safe Thermal Effect (in CAL/SQCM).
27. Sure-Kill Thermal Effect (in CAL/SQCM).
28. Overpressure Fluence (in PSI).
29. Gust Fluence (in FPS).
30. Thermal Fluence (in CAL/SQCM).
31. Overpressure Probability of Survival.
32. Gust Probability of Survival.
33. Thermal Probability of Survival.
34. Aircraft Escape Time (Take-Off Time - Warhead Arrival).
35. Surviving Aircraft Counter.
36. Surviving Bomber Counter.
37. Surviving Tanker Counter.

<u>ATRIB Variables:</u>

1. Time Since Entity Was Created (INT(1)).
2. Aircraft Type (1 = Bomber, 2 = Tanker).

APPENDIX D

Data Set for Multiple Base Simulation

480	7	120	20	100	30	70	20
8	140	40	140	30	60	20	1
400	5	110	25	105	25	65	15
5	120	50	150	25	65	25	2
450	6	115	30	90	45	50	10
6	130	25	155	30	40	15	1
600	4	150	50	110	35	80	20
0	0	0	0	0	0	0	1
530	0	0	0	0	0	0	0
5	200	45	120	30	40	20	1

APPENDIX E

Single Base Simulation SLAM Output

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT BASE ESCAPE   BY SCLARK

DATE 11/12/1985   RUN NUMBER   20 OF   20

CURRENT TIME   .4457E+03
STATISTICAL ARRAYS CLEARED AT TIME   .0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
ELAP TIME	.343E+03	.686E+02	.200E+00	.179E+03	.491E+03	300
ESCAPE TIME	.294E+03	.441E+02	.150E+00	.179E+03	.378E+03	171
BMBR SURV TIME	.292E+03	.431E+02	.148E+00	.179E+03	.372E+03	122
TNKR SURV TIME	.299E+03	.463E+02	.155E+00	.200E+03	.378E+03	49
AVG # AC ESCAPE	.855E+01	.000E+00	.000E+00	.855E+01	.855E+01	1
AVG # BMR ESCAPE	.610E+01	.000E+00	.000E+00	.610E+01	.610E+01	1
AVG # TKR ESCAPE	.245E+01	.000E+00	.000E+00	.245E+01	.245E+01	1
BASE 1 BMR ESC	.610E+01	.641E+00	.105E+00	.500E+01	.700E+01	20
BASE 1 TKR ESC	.245E+01	.110E+01	.449E+00	.100E+01	.500E+01	20
BASE 2 BMR ESC			NO VALUES RECORDED			
BASE 2 TKR ESC			NO VALUES RECORDED			
BASE 3 BMR ESC			NO VALUES RECORDED			
BASE 3 TKR ESC			NO VALUES RECORDED			
BASE 4 BMR ESC			NO VALUES RECORDED			
BASE 4 TKR ESC			NO VALUES RECORDED			
BASE 5 BMR ESC			NO VALUES RECORDED			
BASE 5 TKR ESC			NO VALUES RECORDED			

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	QUEUE	.026	.159	1	0	1.644
2	QUEUE	.000	.000	0	0	.000
3	QUEUE	.261	.534	2	0	14.516
4	QUEUE	.000	.000	0	0	.000
5		.000	.000	0	0	.000
6	CALENDAR	11.021	5.094	18	0	20.466

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION	ENTITY COUNT
1	.0000	.0000	1	0	7
2	1.8779	2.9268	7	0	7
3	1.5203	2.3118	7	0	7
4	1.0714	1.6445	7	0	7
5	.0000	.0000	0	0	0
7	.0000	.0000	1	0	8
8	2.4738	3.2678	8	0	8
9	2.4510	2.6889	8	0	8
10	1.0599	1.4967	7	0	8
11	.0000	.0000	0	0	0
14	.0000	.0000	1	0	9
15	.0000	.0000	1	0	6
20	.0000	.0000	1	0	9
21	.0000	.0000	1	0	0
22	.0000	.0000	1	0	9
23	.0000	.0000	1	0	0
24	.0000	.0000	1	0	2
25	.0000	.0000	1	0	7

SERVICE ACTIVITY STATISTICS

ACT IND	START NODE LABEL/TYPE	SER CAP	AVERAGE UTIL	STD DEV	CUR UTIL	AVERAGE BLOCK	MAX IDL TME/SER	MAX BSY TME/SER	ENT CNT
6	DUA1 QUEUE	1	.000	.00	0	.00	9010.05	.00	0
12	SEL1 SELECT	1	.359	.48	0	.00	263.97	200.82	15
13	DUA2 QUEUE	1	.000	.00	0	.00	9010.05	.00	0

HISTOGRAM NUMBER 1
ELAP TIME

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80       100
                    +    +    +    +    +    +    +    +    +    +    +
  0  .000  .140E+03 +                                                 +
  0  .000  .170E+03 +                                                 +
  3  .010  .200E+03 +                                                 +
 14  .047  .230E+03 +**C                                              +
 21  .070  .260E+03 +**** C                                           +
 36  .120  .290E+03 +******     C                                     +
 39  .130  .320E+03 +******            C                              +
 43  .143  .350E+03 +*******                  C                       +
 47  .157  .380E+03 +********                         C               +
 39  .130  .410E+03 +******                                 C         +
 38  .127  .440E+03 +******                                        C  +
 17  .057  .470E+03 +***                                             C+
  3  .010  .500E+03 +                                                 C
  0  .000    INF    +                                                 C
---                 +    +    +    +    +    +    +    +    +    +    +
300                 0         20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
ELAP TIME	.343E+03	.686E+02	.200E+00	.179E+03	.491E+03	300

HISTOGRAM NUMBER 2
ESCAPE TIME

```
OBS  RELA  UPPER
FREQ FREQ  CELL LIM 0        20        40        60        80       100
                    +    +    +    +    +    +    +    +    +    +    +
   0  .000 .160E+03 +                                                 +
   2  .012 .190E+03 +*                                                +
   7  .041 .220E+03 +**C                                              +
  23  .135 .250E+03 +******* C                                        +
  34  .199 .280E+03 +**********         C                             +
  37  .216 .310E+03 +***********                  C                   +
  40  .234 .340E+03 +*************                            C        +
  25  .146 .370E+03 +*******                                         C+
   3  .018 .400E+03 +*                                                C
   0  .000 .430E+03 +                                                 C
   0  .000 .460E+03 +                                                 C
   0  .000 .490E+03 +                                                 C
   0  .000 .520E+03 +                                                 C
   0  .000   INF    +                                                 C
 ---                +    +    +    +    +    +    +    +    +    +    +
 171                0        20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
ESCAPE TIME	.294E+03	.441E+02	.150E+00	.179E+03	.378E+03	171

HISTOGRAM NUMBER 3
BMBR SURV TIME

```
OBS  RELA    UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80       100
                    +    +    +    +    +    +    +    +    +    +    +
  0  .000  .160E+03 +                                                 +
  2  .016  .190E+03 +*                                                +
  4  .033  .220E+03 +**                                               +
 17  .139  .250E+03 +******* C                                        +
 26  .213  .280E+03 +***********         C                            +
 27  .221  .310E+03 +***********                    C                 +
 28  .230  .340E+03 +***********                                C     +
 17  .139  .370E+03 +*******                                          C
  1  .008  .400E+03 +                                                 C
  0  .000  .430E+03 +                                                 C
  0  .000  .460E+03 +                                                 C
  0  .000  .490E+03 +                                                 C
  0  .000  .520E+03 +                                                 C
  0  .000    INF    +                                                 C
---                 +    +    +    +    +    +    +    +    +    +    +
122                 0         20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
BMBR SURV TIME	.292E+03	.431E+02	.148E+00	.179E+03	.372E+03	122

HISTOGRAM NUMBER 4

TNKR SURV TIME

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0        20        40        60        80        100
                    +    +    +    +    +    +    +    +    +    +    +
  0  .000  .160E+03 +                                                 +
  0  .000  .190E+03 +                                                 +
  3  .061  .220E+03 +***                                              +
  6  .122  .250E+03 +******  C                                        +
  8  .163  .280E+03 +********        C                                +
 10  .204  .310E+03 +**********                 C                     +
 12  .245  .340E+03 +************                           C         +
  8  .163  .370E+03 +********                                       C +
  2  .041  .400E+03 +**                                               C
  0  .000  .430E+03 +                                                 C
  0  .000  .460E+03 +                                                 C
  0  .000  .490E+03 +                                                 C
  0  .000  .520E+03 +                                                 C
  0  .000    INF    +                                                 C
 ---                +    +    +    +    +    +    +    +    +    +    +
 49                 0        20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
TNKR SURV TIME	.299E+03	.463E+02	.155E+00	.200E+03	.378E+03	49

APPENDIX F

Five Base Simulation SLAM Output

S L A M   S U M M A R Y   R E P O R T

SIMULATION PROJECT BASE ESCAPE   BY SCLARK

DATE 11/12/1985   RUN NUMBER 100 OF 100

CURRENT TIME .4390E+03
STATISTICAL ARRAYS CLEARED AT TIME .0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
ELAP TIME	.330E+03	.679E+02	.206E+00	.987E+02	.503E+03	920
ESCAPE TIME	.296E+03	.571E+02	.193E+00	.145E+03	.476E+03	513
BMBR SURV TIME	.287E+03	.597E+02	.208E+00	.145E+03	.476E+03	334
TNKR SURV TIME	.314E+03	.468E+02	.149E+00	.200E+03	.412E+03	179
AVG # AC ESCAPE	.256E+02	.000E+00	.000E+00	.256E+02	.256E+02	1
AVG # BMR ESCAPE	.167E+02	.000E+00	.000E+00	.167E+02	.167E+02	1
AVG # TKR ESCAPE	.895E+01	.000E+00	.000E+00	.895E+01	.895E+01	1
BASE 1 BMR ESC	.610E+01	.641E+00	.105E+00	.500E+01	.700E+01	20
BASE 1 TKR ESC	.245E+01	.110E+01	.449E+00	.100E+01	.500E+01	20
BASE 2 BMR ESC	.220E+01	.951E+00	.432E+00	.000E+00	.400E+01	20
BASE 2 TKR ESC	.600E+00	.883E+00	.147E+01	.000E+00	.300E+01	20
BASE 3 BMR ESC	.505E+01	.686E+00	.136E+00	.400E+01	.600E+01	20
BASE 3 TKR ESC	.220E+01	.128E+01	.582E+00	.000E+00	.500E+01	20
BASE 4 BMR ESC	.335E+01	.671E+00	.200E+00	.200E+01	.400E+01	20
BASE 4 TKR ESC	.000E+00	.000E+00	.100E+05	.000E+00	.000E+00	20
BASE 5 BMR ESC	.000E+00	.000E+00	.100E+05	.000E+00	.000E+00	20
BASE 5 TKR ESC	.370E+01	.801E+00	.217E+00	.200E+01	.500E+01	20

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAIT TIME
1	QUEUE	.000	.000	0	0	.000
2	QUEUE	.000	.000	0	0	.000
3	QUEUE	.000	.000	0	0	.000
4	QUEUE	.000	.000	0	0	.000
5		.000	.000	0	0	.000
6	CALENDAR	4.366	1.139	8	0	13.311

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION	ENTITY COUNT
1	.0000	.0000	1	0	0
2	1.2776	2.1964	7	0	0
3	1.0294	1.6817	7	0	0
4	.6708	1.1876	7	0	0
5	.0000	.0000	1	0	0
7	.0000	.0000	1	0	5
8	1.6685	2.4760	8	0	5
9	1.6191	2.1295	8	0	5
10	.5843	1.0553	7	0	5
11	.0000	.0000	1	0	0
14	.0000	.0000	1	0	3
15	.0000	.0000	1	0	2
20	.0000	.0000	1	0	3
21	.0000	.0000	1	0	0
22	.0000	.0000	1	0	3
23	.0000	.0000	1	0	0
24	.0000	.0000	1	0	3
25	.0000	.0000	1	0	0

SERVICE ACTIVITY STATISTICS

ACT IND	START NODE LABEL/TYPE	SER CAP	AVERAGE UTIL	STD DEV	CUR UTIL	AVERAGE BLOCK	MAX IDL TME/SER	MAX BSY TME/SER	ENT CNT
6	DUA1 QUEUE	1	.019	.14	0	.00	24893.93	93.23	0
12	SEL1 SELECT	1	.130	.34	0	.00	8643.34	200.82	5
13	DUA2 QUEUE	1	.019	.14	0	.00	24769.17	75.05	0

```
                                **HISTOGRAM NUMBER 1**
                                     ELAP TIME
 OBS   RELA    UPPER
 FREQ  FREQ  CELL LIM 0         20        40        60        80        100
                      +    +    +    +    +    +    +    +    +    +    +
   1   .001  .140E+03 +                                                 +
   6   .007  .170E+03 +                                                 +
  18   .020  .200E+03 +*                                                +
  44   .048  .230E+03 +**  C                                            +
  84   .091  .260E+03 +*****   C                                        +
 104   .113  .290E+03 +******        C                                  +
 141   .153  .320E+03 +********              C                          +
 150   .163  .350E+03 +********                     C                   +
 146   .159  .380E+03 +********                             C           +
 113   .123  .410E+03 +******                                     C     +
  76   .083  .440E+03 +****                                           C +
  26   .028  .470E+03 +*                                               C+
  10   .011  .500E+03 +*                                                C
   1   .001    INF    +                                                 C
 ---                  +    +    +    +    +    +    +    +    +    +    +
 920                  0         20        40        60        80        100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
ELAP TIME	.330E+03	.679E+02	.206E+00	.987E+02	.503E+03	920

HISTOGRAM NUMBER 2
ESCAPE TIME

```
 OBS  RELA  UPPER
FREQ  FREQ  CELL LIM 0         20        40        60        80       100
                     +    +    +    +    +    +    +    +    +    +    +
   3  .006  .160E+03 +                                                 +
  16  .031  .190E+03 +**                                               +
  28  .055  .220E+03 +*** C                                            +
  69  .135  .250E+03 +*******   C                                      +
  89  .173  .280E+03 +*********          C                             +
  94  .183  .310E+03 +*********                   C                    +
 102  .199  .340E+03 +**********                            C          +
  61  .119  .370E+03 +******                                      C    +
  29  .057  .400E+03 +***                                            C +
  19  .037  .430E+03 +**                                               C
   2  .004  .460E+03 +                                                 C
   1  .002  .490E+03 +                                                 C
   0  .000  .520E+03 +                                                 C
   0  .000    INF    +                                                 C
 ---                 +    +    +    +    +    +    +    +    +    +    +
 513                 0         20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO. OF OBS
ESCAPE TIME	.296E+03	.571E+02	.193E+00	.145E+03	.476E+03	513

HISTOGRAM NUMBER 3
BMBR SURV TIME

```
OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80       100
                    +    +    +    +    +    +    +    +    +    +    +
  3  .009  .160E+03 +                                                 +
 16  .048  .190E+03 +**C                                              +
 23  .069  .220E+03 +***  C                                           +
 55  .165  .250E+03 +********      C                                  +
 66  .198  .280E+03 +**********             C                         +
 57  .171  .310E+03 +*********                       C                +
 54  .162  .340E+03 +********                                C        +
 34  .102  .370E+03 +*****                                        C   +
  9  .027  .400E+03 +*                                             C  +
 14  .042  .430E+03 +**                                               C
  2  .006  .460E+03 +                                                 C
  1  .003  .490E+03 +                                                 C
  0  .000  .520E+03 +                                                 C
  0  .000    INF    +                                                 C
---                 +    +    +    +    +    +    +    +    +    +    +
334                 0         20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
BMBR SURV TIME	.287E+03	.597E+02	.208E+00	.145E+03	.476E+03	334

```
                    **HISTOGRAM NUMBER 4**
                         TNKR SURV TIME

OBS  RELA   UPPER
FREQ FREQ  CELL LIM 0         20        40        60        80       100
                    +    +    +    +    +    +    +    +    +    +    +
   0 .000  .160E+03 +                                                 +
   0 .000  .190E+03 +                                                 +
   5 .028  .220E+03 +*                                                +
  14 .078  .250E+03 +****C                                            +
  23 .128  .280E+03 +******     C                                     +
  37 .207  .310E+03 +**********          C                            +
  48 .268  .340E+03 +*************                    C               +
  27 .151  .370E+03 +********                                 C       +
  20 .112  .400E+03 +******                                          C+
   5 .028  .430E+03 +*                                                C
   0 .000  .460E+03 +                                                 C
   0 .000  .490E+03 +                                                 C
   0 .000  .520E+03 +                                                 C
   0 .000    INF    +                                                 C
---                 +    +    +    +    +    +    +    +    +    +    +
179                 0         20        40        60        80       100
```

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TNKR SURV TIME	.314E+03	.468E+02	.149E+00	.200E+03	.412E+03	179

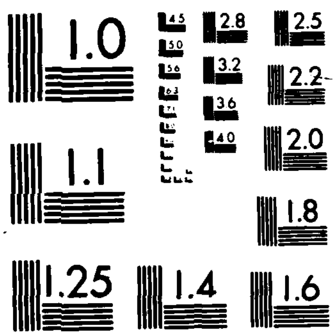
APPENDIX G

Multiple Regression Input Data

RUN	TIME	YIELD	HOB	CEP	OPRES	GUST	THERM
1.	1	1	0	0	.219	.396	.298
2.	-1	1	0	0	15.1	183	159
3.	-1	-1	0	0	2.54	34.5	10.7
4.	1	-1	0	0	.149	.222	.114
5.	0	0	1	1	.987	4.91	2.81
6.	0	0	-1	1	.789	3.46	1.63
7.	0	0	-1	-1	.754	.889	.571
8.	0	0	1	-1	1.06	1.24	2.02
9.	1	0	0	1	.196	.356	.215
10.	-1	0	0	1	9.23	171	76.5
11.	-1	0	0	-1	10.8	55.6	78.7
12.	1	0	0	-1	.195	.336	.205
13.	0	1	1	0	.891	2.46	5.64
14.	0	-1	1	0	.313	.763	.223
15.	0	-1	-1	0	.328	.782	.228
16.	0	1	-1	0	.998	2.93	1.92
17.	1	0	1	0	.194	.329	.238
18.	-1	0	1	0	4.34	44.5	51.4
19.	-1	0	-1	0	18.4	317	136
20.	1	0	-1	0	.197	.344	.211
21.	0	1	0	1	1.40	6.35	4.71
22.	0	-1	0	1	.271	.935	.425
23.	0	-1	0	-1	.261	.288	.317
24.	0	1	0	-1	1.33	1.57	3.19
25.	0	0	0	0	1.04	2.99	2.10

AD-A172 402 A SLAM SIMULATION BASE ESCAPE MODEL USING RESPONSE SURFACE METHODOLOGY(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING 2/2

UNCLASSIFIED S P CLARK MAR 86 AFIT/GST/OS/86M-3 F/G 1/2 NL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2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

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Abstract

This thesis presents a microcomputer compatible, base escape nuclear survivability model specifically designed to compute pre-launch survivability. It computes the number of aircraft surviving from single or multiple bases under SLBM attack. The model concentrates on simulating the process from alert to take-off. In particular, it models the statistical variability of crew reaction time, engine start time, taxi time, and take-off separation time under various levels of readiness. Nuclear overpressure, gust, and thermal fluences are determined through response surface methods and aircraft survivability is derived from cumulative log-normal damage functions. Its advantages over current base escape models are microcomputer compatibility and stochastic representation of the pre-launch survivability timing variables.

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